PRESSWORKING
OF METALS

A reference book illustrating and describing
practical applications of the principles used
in the design of punches and dies

BY

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PRESSWORKING OF METALS

PREFACE

This book is a more comprehensive treatment of the information contained in a series of thirty articles that appeared in *The American Machinist* in 1938 and 1939. The number of illustrations and the length of the text have been doubled.

The large number of requests for additional copies of the magazine installments indicated an urgent demand for a book of this character. Inquiries came from large manufacturers, employers, toolmakers, and die engineers, from such widely separated areas as New England, New York City, Texas, Ontario, the Middle West, and the South. They called for additional literature concerning the pressworking qualities of metals, types of presses and accessories, and the principles of the design and construction of dies. This book, written by a member of the tool-engineering profession in terms and phraseology that die men are familiar with, endeavors to supply the necessary information.

The physical properties of metals are given for strips and sheets and refer to the workability of those materials which are used exclusively in presswork. This convenience saves much of the reader's time. It eliminates the confusion that always arises in connection with information sought in general handbooks that include turning, boring, drilling, milling, heat-treating, or casting of the metal under consideration.

Some of the information given may be elementary to a professional, but its inclusion was found necessary to make this work complete. Charts and diagrams cannot be read accurately unless so greatly enlarged that legibility becomes easy without a glass, and charts of this size are often not feasible. Simple mathematical formulas are therefore used in this book in place of nomographic charts and diagrams.

It has been the constant aim to present the mechanical problems in die engineering from the standpoint of the principle involved. This feature eliminates large drawings and a confusion of lines—such as those for automobile-body dies—and the long, tiresome descriptions of individual tools, which serve no particular purpose. In this way the engineering principles have been emphasized. They stand out clearly for other applications in an endless variety of tool designs.

Although most of the die problems introduced are for fabricating light parts, the principles revealed are applicable for pressworking parts of any size.

An important law in die engineering is that a proper subdivision of operations is a function of accuracy. The essence of this is that any function can be successfully consummated in a sufficient number of operations. Nowhere in all the profession of tool and machine engineering does this law apply more truly than in the plastic working of metals. The only drawback in following this law is its direct opposition to the principle of economic production. In other words, presswork must be finished in as few operations as possible.

However, in a sufficient number of operations, low brass and open-hearth steel can be worked more economically, and these operations are preferable for certain results. It is not impossible to draw a wash basin from a cast-iron blank, given time and enough operations. Knots have been tied in piston rings, and cast-iron parts have been forged on a production basis. This proves that all metals are subject to plastic flow if given time and if properly normalized between operations.

The mathematics of tools and machines is the vital principle that determines the fixed mechanical relationship between all the parts. It determines the shapes, sizes, and operating clearances between working parts. No one who designs or constructs anything can avoid mathematics. Mathematics is inherent in every step of all mechanical designs and operations. The inclusion of shop mathematics was therefore thought to be necessary. There are probably too few practical applications for higher mathematics in ordinary tool engineering to reimburse one for the time spent in this line of study.

The author is pleased to extend acknowledgments to his many friends and business associates for the timely suggestions and valuable cooperation they so willingly gave him in the preparation of this book. First among them is Rupert Le Grand, Detroit editor of *The American Machinist.* Mr. Le Grand obtained most of the photographs for the types of presses. He made personal contacts with several large press manufacturers to obtain the pictures and also obtained assistance from them in checking and editing some of the text for the serial installments.

The press and equipment manufacturers who gave valuable assistance are E. W. Bliss Company; Chambersburg Engineering Company; Cleveland Punch & Shear Works Company; Consolidated Press, division of E. W. Bliss Company; General Machinery Co.; Greenerd Arbor Press Company; Henry & Wright Manufacturing Company; Marquette Tool & Manufacturing Company; Niagara Machine & Tool

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C. W. HINMAN.

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PRESSWORKING OF METALS

CHAPTER I

INTRODUCTION

Pressworking of metals involves three outstanding factors: the press, the work material, and the die. This book aims to review these fundamentals in the order named. Metalworking presses may be subdivided into numerous classified groups in which each type of machine produces efficient results within its respective range and capacity. These groups are illustrated, discussed, and classified under Types of Presses and Their Selection, Chap. II.

When installing new presses, it is best to purchase only one standard make. This policy has been found to improve shop layout, to effect economies in repair, and to simplify the assignment of work. Whether you are in agreement with this policy or not—and it is freely admitted that there are certain presses of a different make that fit in better than those of the make chosen—it is an indication of good management to standardize the recess in the slide for punch-holder stems and also the sizes of bolster plates, the location of bolt holes, and clamps and fastenings, so far as possible.

Thirty years ago many dies were in common use without substantial guide posts and guide bushings. With thin stock and little or no punch clearances, and with loosely worn slides, chipped die edges and frequent regrindings were the regular program. Occasionally the press was found in which a bushing was used instead of V-blocks to hold the punch stem. The setscrew in front usually distorted the bushing and of course produced a burr. After a while the punch was not held straight, the resulting work was burred, and the die had to be reground too often. Compared with the die and press equipment of today, these conditions of the past reveal our present strides forward. By such experiences the futility of attempting to cut thin blanks without using the guidepost type of dies was learned. Today, it is a wonder how the past generation ever produced any satisfactory presswork. If the author has learned anything from his thirty-five years of experience in interchangeable manufacturing, it is that perfect results come only from perfect conditions.

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In regard to safety appliances, it is well to remember that a small bench press will crush fingers just as easily as a large press will. A small press may be even more dangerous, because it operates faster. It is best to install some kind of automatic feed or to encase the punch in a glass or net with a lamp inside shining on the die but shielded from the operator's eyes. A little hand slide should be made and attached to feed the parts under the punch.

In bending, forming, and assembling dies—if the work clings to the punch—arrange a side cam, latches, or hooks that will eject the piece when the ram ascends. This relieves the operator from removing the piece by hand—always a dangerous procedure. If a tool can be so designed as to give the operator a sense of safety, it improves operating conditions and increases output. Frankly, there is not a single practical safety device for a hand-feed press. Most of them can be made inactive by a dishonest operator who tries to "beat the rate"; otherwise the device tends to retard fast work.

Among the best safety appliances are the photoelectric cell devices, but some press operators are even skeptical about these because they seem so intangible.* But aside from all this, safety devices either do not fully protect, or they slow down production. So, for maximum safety, especially for women operators, an automatic feed of some sort is necessary, or the encasement of the die in glass or screen is advocated.

The types, sizes, capacities, and uses of individual presses are many. It is doubtful if anyone can recall even a few of them, from the foot press up to the modern 5,500-ton hydraulic aircraft presses. At one time or another most tool engineers have had experience with practically every kind of press made in the United States and with some of those made in foreign countries. Each machine, moreover, was found efficient within its intended range and capacity. Comparatively speaking, the ordinary punch press is a simple machine. There are no outstanding basic patents that give any one manufacturer a decided advantage over his competitors. Recent high-speed presses can hardly be classed with ordinary presses. They should be classed with machines and belong with other similar types, such as the Multi-slide Machine.

Intelligent planning and layout of press tools depend upon a thorough knowledge of the characteristics and dimensions of the equipment available in the shop. Both the production man and the die engineer must give consideration to the kind of press that should be used on a given job, its speed, its ram and bed dimensions, the length

* John Long, "The Electric Eye in Industry," *Product Engineering,* January, 1940, discusses the safety value of using the photoelectric cell in connection with power presses.

of its stroke, the effectiveness of its crankshaft at the point in the stroke where maximum pressure is required, the feeding arrangement or method of handling the work into and out of the press, and the press deflection that is permissible. Many of these factors can be known in advance by a convenient tabulation of dimensional data.

Chapter II gives a ready reference classification of the more common types of presses. The main subdivisions are gap-frame presses, straight-side frame presses, Super-Speed Presses, and drawing presses. Countless names are used to designate presses, but the ones chosen are generally accepted. High-speed presses and drawing presses are segregated from the other types, irrespective of frame construction, because they apply only to mass production or to a specified process. Information on the selection of presses with regard to capacity and peculiarities of the work follows the major subject on the types of machines available.

An important consideration in selecting a press is the possible deflection that may be expected. Press materials as well as die materials are elastic. Gap presses will deflect more than straight-side presses, in the plane of the tools, because the throat tends to open when punch pressure is applied. On a great many jobs, deflection of gap presses is unimportant and is overshadowed by the ease of handling the work into and out of the dies. Tie rods may be affixed across the gap to control deflection. This may make the press less accessible for hand feeding but will create no hindrance in presses using roll feeds. Work that requires high-grade accuracy or exceptionally heavy pressure is usually fabricated in straight-side presses.

The use of a good microscope of at least 50 diameters magnification is an indispensable aid in shops and designing offices. Experience has taught that many irregularities in work frequently begin by imperfections too obscure for the naked eye to detect. This may also suggest that certain machine and tool designs may have gone astray because the designer did not possess a microscopic knowledge of the work.

It is customary to think that our own business is different from every other. This is not so. There are very few mechanical principles and basic operations. It is merely a different combination of these principles and operations that makes all the different mechanical trades and businesses. Different machines are simply other combinations of the same mechanical movements. For example, an automobile motor and a punch press may seem to be entirely different, but they both use similar crank motions. The motor receives power impulses at the end of a reciprocating ram (piston) and delivers rotary motion through a crank to a flywheel. A punch press receives power

at the flywheel and delivers reciprocating motion through a crank to the working end of the ram. Recognition of this universality in mechanical motions gives one a broader view and helps to solve many problems.

The first procedure in designing a press tool is to get an accurate mental picture of the operation and the results expected. For designing intricate dies of progressive types write an outline of the sequence of operations, and then make several freehand sketches from the outline. If the sketches appear to represent practical diemaking principles, prove them by making sketches drawn to scale.

The best tool designs are the simplest. No tool needs unnecessary screws, dowel pins, or parts. Working members should be as few as possible. They should be designed for easy machining, with difficult cuts and unnecessary handwork eliminated. Tool-steel parts should be of shapes that are easy to harden and temper without distortion. Die blocks should be divided where small irregular openings occur; the openings can then be worked out in halves. Press tools must be of rugged construction. They must be built so that they are strong enough to resist high percussion blows. They must stand up and work, despite the millions of hammering blows delivered by high-powered presses. This means that crystallization, fissures, fractures, and breaks are contending factors. Cutting, drawing, and forming members in dies must have greater cross-sectional areas and strength than for ordinary tools.

Modern drafting offices are usually supplied with the comparatively recent equipment for making black-, brown-, or red-line prints on white-paper backgrounds. These prints are useful when starting the design of a new tool or machine. Make a red-line print of the proposed work, and then design the tool or machine around the work. An advantage in this method is that any reasonable number of erasures can be made without destroying the indelible red lines. When arriving at a satisfactory design, make a tracing of the combined work and tool on a permanent assembly sheet, preparatory to detailing.

A die design may appear impractical until analyzed by looking at the drawing from the top down. Thus, by turning the drawing around 180 deg. and analyzing the operating conditions, it may be found that an inverted compound die is more practical. In this type, the die block is the upper or moving member, and the punch below is stationary. Inverted compound dies provide a better means for disposing of pierced slugs and scrap and an easy method for separating the work and scrap and for ejecting the finished piece. The inverted test for die drawings is particularly applicable in multiple-station progressive dies.

When the application of any mechanical principle or movement seems to indicate that it may not function properly in the design at hand, ascertain by a series of sketches in how many different ways the proposed movement can be made to function, and then choose the one that experience shows will function best. It is sometimes expedient to prepare cardboard templates of tentative mechanical movements and then by laying them on the board—with pins pushed through at fulcrum centers—to determine the exact movements and the necessary operating clearances.

The best information a die engineer can possess is practical knowledge of the basic principles in die design and construction. This can be attained only through years of practical experience. An expert is not one who knows every detail but one who can reason in terms of fundamentals and is able to visualize and foresee the failures that will surely occur when these fundamentals are neglected.

In no other era of time have there been such great strides forward in the pressworking of metals as in the present. Hardly a day passes that we do not hear of new materials, new tools and machines that produce better results by increased outputs and improved manufacturing processes. A perusal of the several mechanical periodicals, with which every designing office should be supplied, helps one to keep in touch with modern methods. There are numberless book publications that reveal the principles, details, and methods for handling most design problems in which we may be interested. Technical libraries may be found in many of the larger towns; they are usually able to furnish the latest procedure and reports of several national engineering societies.

Chapter XXIII presents simple mathematical formulas for die construction and press operation. These, together with the tables and diagrams, were all taken from those used in actual practice. Much of this information is comprised of short-cut mathematical formulas, especially those given for calculating blank sizes for drawn shells. Many of these formulas and diagrams were derived on occasion to solve dimensional computations that seemed likely to arise again. These data have withstood all the tests of trial and time. It is hoped that designers and toolmakers who encounter similar problems will find their solution here or a suggestion that points the way to a solution.

In the following pages an attempt has been made to illustrate and describe—as one die engineer would to another—some of the outstanding principles as applied in the design, construction, and operation of dies for pressworking of metals in conjunction with modern types of power presses, press attachments, and accessories.

Notching Press

90-Deg. Inclined Press

Inclinable Press

Bench Press

Foot Press

Open-Back Gap Press

Double-Crank Overhanging Press

Harning Press

End-Wheel Gap Press
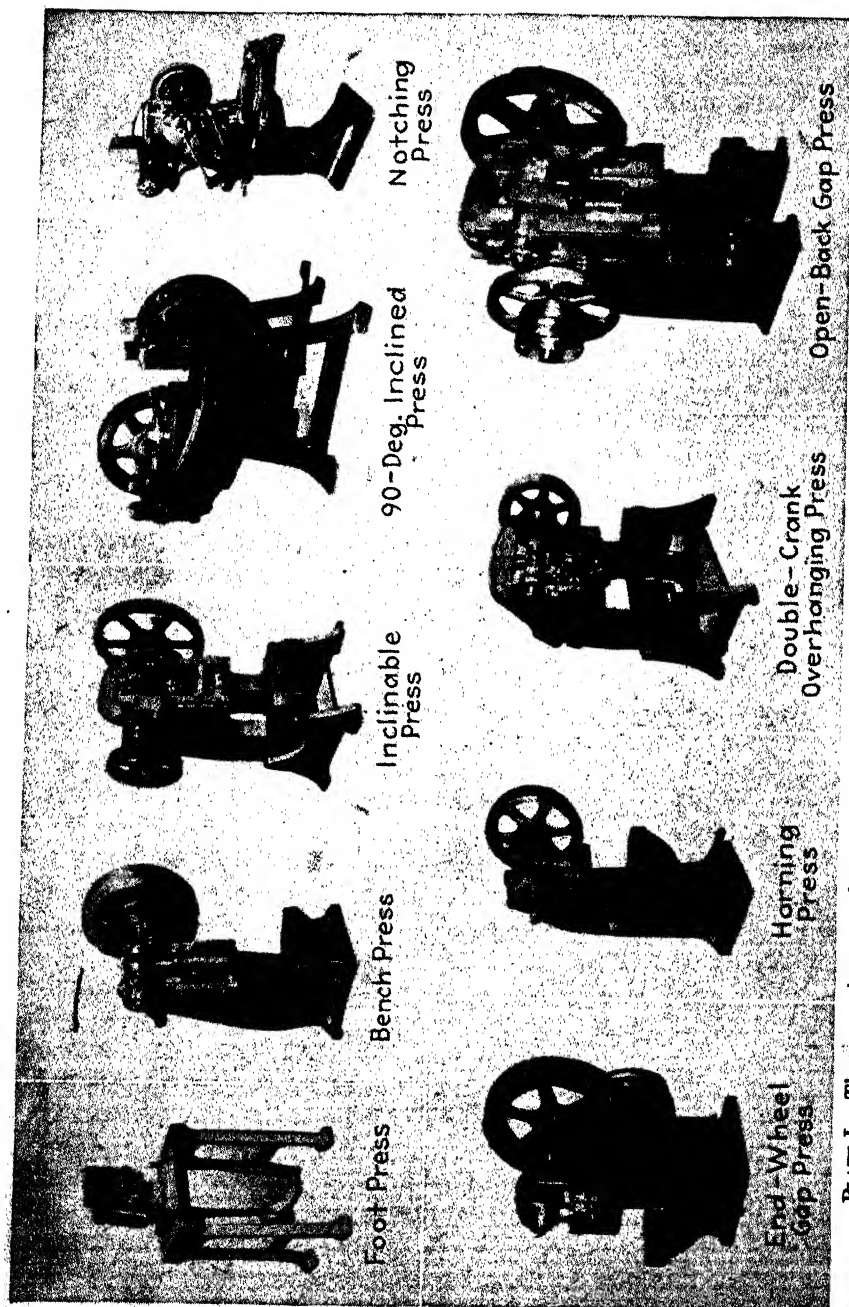
PLATE I.—There are nine general types of Gap Frame Press, and each one is designed for some specific purpose.

TYPES OF PRESSES AND THEIR SELECTION

GAP-FRAME PRESSES

Foot Presses.—These presses are the least powerful machines used for presswork operations. Two general types of foot presses are available: plain-toggle joint and toggle-lever joint. In both types the ram is actuated by a foot-lever pendulum, and the toggle-lever type has a weighted pendulum to increase the momentum.

Foot presses are usually independent units supported on four legs, but the legs can be detached for mounting the press on a bench. These presses are useful for small assemblies where the parts are folded or pressed together after being started by hand. There are staking jobs so delicate that the minimum variation in work thickness would cause a power press either to overstake or to understake, and there are single small holes, or light stampings, that can be more effectively produced in a foot press.

These presses are used ordinarily for forming, embossing, or stamping in the manufacture of buckles, buttons, jewelry, pocketbook frames, silverware, telephones, typewriters, radios, and similar light assemblies.

Foot Press with Adjustable Bed or Horn.—The advantage in using this type of press is obvious. The bed can be adjusted up or down a distance of 5 in. to accommodate large or small work. A horn can be substituted in place of the bed for taking hollow or open work. The press is either used on the cast frame and legs or removed from the legs and mounted on a bench.

Bench Presses.—Next in size to the foot press is the bench press. This machine is practically a miniature of larger presses and is adapted to almost every type of press operation. Machines of this class are used for manufacture of buttons, jewelry, watch parts, toys, and novelties. Capacities range from 1,000 lb. to 12 tons. Roll feeds, ratchet dials, magazines, sliding-die feeds, and automatic feeds may be applied to increase the output.

Inclinable Presses.—Next in size above the bench press are fly-wheel inclinable presses and back-geared inclinable single-action presses. Machines of these classes cover the majority of requirements

ARCH PRESS

SINGLE-ACTION
PRESS
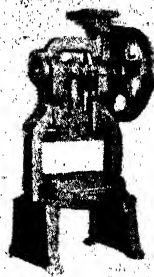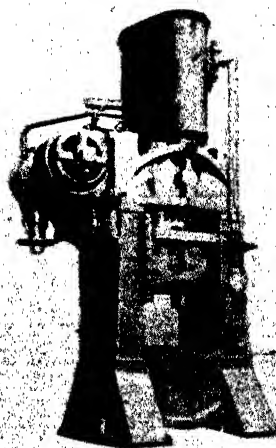
HYDRAULIC COIN-
ING AND EM-
BOSSING PRESS

KNUCKLE-JOINT
PRESS

PLATE II.—Straight-side presses.

TRIPLE-ACTION
PRESS

FOUR-POINT
SUSPENSION PRESS
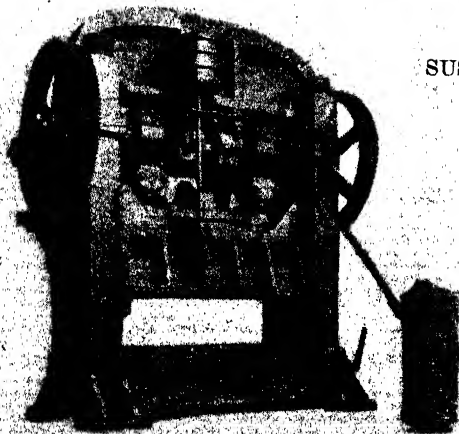
DOUBLE-CRANK
SINGLE ACTION PRESS

PLATE III.—Straight-side presses.

for single-action and combination die work on small articles and parts in comparatively light sheet metal. Their use includes blanking, forming, bending, light stamping, and assembling. With the proper drawing attachments they are applicable to drawing work in cups and small shells.

The angle of inclination usually ranges from vertical to 45 deg. backward, but one type is inclinable 90 deg. to attain greater use of gravity in ejecting the work. The horizontal position also aids the placing of long work in the dies for assembling operations. Feeding attachments of all kinds can be furnished. Capacities of inclinable presses range from 4 to 90 tons at the bottom of the stroke.

Open-back Gap Presses.—This type of frame is similar to the inclinable press except that it does not incline. The gap press is in great demand for use where strips or sheets of metal must be fed across the die or where operations are to be performed on a product that is large or irregular. Gap presses can accommodate large-area dies and are convenient for the arrangement of roll or dial feeds. The ram is driven by either a crank or an eccentric motion. The latter is especially suited for punching, shearing, cutting out, and forming blanks of heavy metal and for operating trimming and forming dies used in the manufacture of agricultural implements, automobiles, cash registers, clocks, and other articles made of bar and sheet steel. Capacities range from 1 to 225 tons.

End-wheel Gap Presses.—End-wheel gap presses have the fly-wheel at the rear and the crankshaft at right angles to the length of the bed. This construction is valuable for heavy work in long narrow strips, such as piercing, notching, cutting off, blanking, or forming. It is also used for a wide variety of other purposes, ranging from sub-press dies for watch parts to wide-deep-throated blanking dies to wiring, seaming, and similar work. Capacities range from bench sizes to 50 tons, when the machines are called "power-punching presses."

Deep-gap Punch Presses.—Deep-gap punch presses are designed with a deep clearance gap in the back frame, between the bed and ram slides, in order to handle wide sheets.

Horning Presses.—Horning presses are built upright and cannot be inclined. A horn is bolted solidly to the frame for holding work such as a small steel drum while setting down the seam. Such presses are also available with swinging tables having a large opening for push-through work. The swinging table can also be raised or lowered to suit the die height. With the table in position, the press has many applications for such work as blanking, stamping, forming, and wiring. Horn presses are often supplied with a heavy flywheel and a short

stroke for heavy punching and riveting. Capacities range from 10 to 100 tons.

Double-crank Overhanging Presses.—Double-crank overhanging presses afford convenience in handling large, irregular sheets of metal, because the cutback, or overhanging, frame gives a large, unobstructed die space. Presses of this class are well adapted for automatic and semiautomatic feeding attachments. Such presses can be used for blanking, cutting, and perforating comparatively thin stock. They are usually driven direct by flywheel, but larger machines are available in single-, double-, or triple-geared design.

Notching Presses.—Notching presses are short-stroke machines, usually 1-in. stroke, for cutting slots in the peripheries of motor laminations. The circular work fixture is driven by a rocker arm operated by the crankshaft. At each index, a locking pawl engages the fixture and holds the work stationary, while the punch and die are engaging to cut the slot. The feed usually is between 450 and 650 strokes per minute.

STRAIGHT-SIDE PRESSES

Single- and Double-action Presses.—Straight-side presses are built either plain or geared and with single, double, or triple connections between the ram and shaft. Straight-side construction consists of a base, two uprights, and a crown. Usually the frame is tied together with four heavy steel tie rods which take the pressure strains. The uprights themselves are heavy enough to withstand lateral stresses which may occur when the slide is unevenly loaded. Presses of this type of construction are capable of operating dies for the heaviest kind of work. Usually the face of the ram of a straight-side press is provided with a dovetailed slot from front to back to facilitate using subpress dies on accurate work.

Arch Presses.—One of the smaller straight-side presses is the arch type. Its utility lies in the large area of bed and slide in proportion to shaft size and the advantages of the straight-side type of frame. The field for these presses is mainly light, large-area sheet-metal work involving blanking, cutting, trimming, shaping, stamping, and large-area lettering. They can also be used for general combination die work. The piece is passed through from front to back, which is a slower method of feeding than from right to left. In some instances arch presses are built with exceedingly high die space and very long strokes for special uses. Most straight-side presses must be fed from front to back.

Double-crank Straight-side Presses.—These presses are built in about 150 standard sizes. Regular uses for this line include blanking, punching, cutting, bending, shaping, forming, and stamping of an unusually large number of articles. Often the slide is counterbalanced by means of an air cylinder and reservoir. Such presses are built as plain flywheel and single, double, and triple geared. Where necessary, as for instance on a very wide- or long-stroke press, the twin-driven type is used rather than that driven only from one end. Capacities up to 2,000 tons at the bottom of the stroke are available.

Four-point Suspension Presses.—When huge pieces such as steel tops for automobile bodies are to be drawn, a four-point suspension press will be chosen. The feature of this design is the fact that an almost absolutely even pressure is exerted on the four corners of the slide, which is a valuable feature when large unbalanced dies are being operated.

Pneumatic cushions can be set directly into the bed of the press for such deep-drawing operations as fenders, thus giving a more compact setup than when drawing cushions are used in combination with the conventional straight-side press. Capacities range from 100 to 1,500 tons.

Knuckle-joint Presses.—Of recent years the knuckle-joint embossing press has come into more extended use. Originally employed for coining money, it is now applied to cold squeezing, swaging, upsetting, embossing, and extruding. Bosses on forgings can be sized as well by coining as by machining. In fact, bosses can be swaged up from flat sheet stock that would be impossible or very expensive by other methods. Pressures up to 100 tons per square inch can be applied to the material. The limitation of the knuckle-joint press is the short stroke, a knuckle-joint operating the slide. Modern knuckle-joint presses involve forced-feed lubrication systems at all main points where heavy pressures on the bearings or other moving parts occur. Above the slide are spring-loaded rods so that the upper block will yield when adjusting the wedge. Capacities range from 25 to 2,500 tons.

HIGH-SPEED PRESSES

Straight-side High-speed Press.—In one make of high-speed press, the basic design involves a straight-side machine equipped with a high-speed roll feed at one end and a scrap cutter at the other end. Massive construction in the upright, crown, and bed eliminates vibration in the machine itself and in the very accurate feeding mechanism. When built with short strokes, this press operates at 400 r.p.m. Automatic force-feed lubrication and individual drive through V-belts connected

to a variable-speed motor are modern features.   The variable-speed motor permits the press to be run at the most suitable speed for the work.   Capacities range from 10 to 400 tons.

Dieing Machine.—Dieing machines are also built vertically, but the ram is operated by four vertical rods passing down through the

Straight-Side Press With Roll Feed

Dieing Machine

Oscillating-Die Press

Multi-Slide Machine
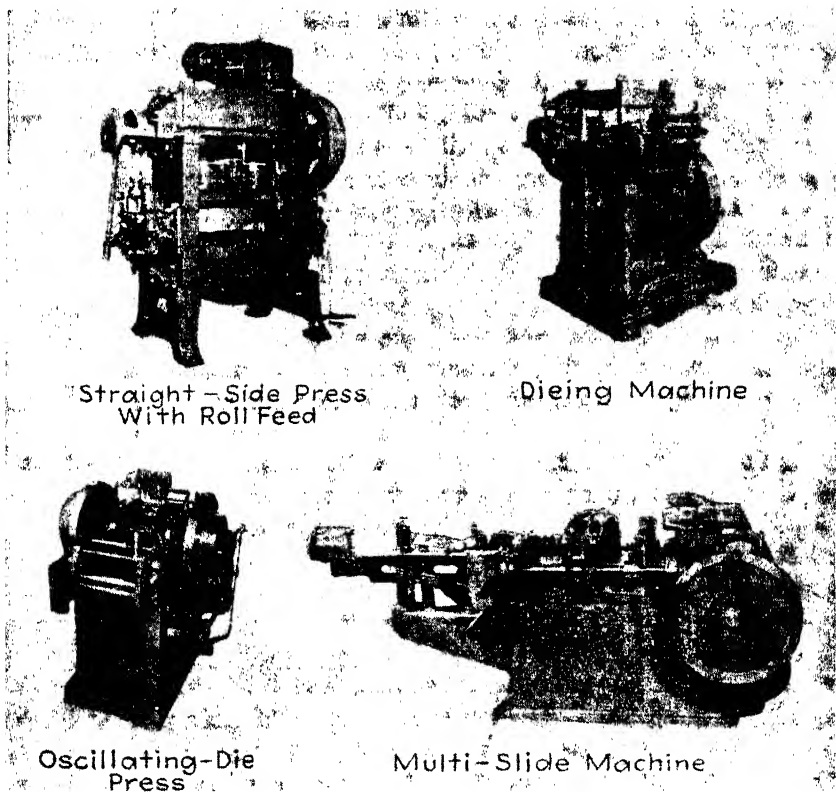
PLATE IV.—High-speed presses. Several types of high-speed press are available or production speeds as high as 1,500 strokes per minute on a conservative basis. Their use is confined to sheet-metal plants where comparatively small articles are manufactured in large quantities, such as in the radio and electrical industries and in plants producing small automobile stampings, chain links, light washers, and safety-razor blades.

bed where they are attached to a plate connected to the driving crank. Thus, a pulling stroke is applied to the die instead of the usual pushing stroke.   The machine is adapted to progressive-die operation, but all varieties of press tool work can be fabricated. Machines in the smaller sizes run at 350 strokes per minute.

Oscillating-die Press.—Another design of high-speed press feeds the strip steadily into an oscillating die.   The bed, or plate upon which the die is mounted, is horizontally reciprocated by an eccentric driving crank.   Lateral movement of the die is in the same plane and direction in which the strip is fed.   The ram with punches attached is vertically operated parallel with the die and, being driven by the same crank that drives the plate, necessarily follows the die.   Instead of following the conventional vertical stroke fixed at one place, the tool moves rapidly from right to left coincident with the feed of the material, while the cutting members are rapidly opening and closing on the strip.   The strip, instead of pausing at blanking centers for operations, passes uninterruptedly through the die.   The press operates at 1,000 strokes per minute.   The fabricated parts are small and of light-gage materials.

Multi-slide Machine.—The horizontal multi-slide machine is largely a modification of the wire-bending and -forming machine and is used for light operations on thin-gage materials.   Accurate feeds to 0.0005 in., the performing of as many as eight operations, and output up to 300 pieces per minute make the multi-slide machine attractive for light jobs that may involve blanking, forming, bending, and assembly with other parts.   In general, the machine notches the blank outline at one or more stations, the part remaining attached to the strip by a small neck.   Bending, forming, and assembly operations follow and are usually done before the piece is cut off.   Strip passes through the machine from left to right with one edge up, and simple tools perform the various operations.

Double-action Presses.—There are several other important types of presses and metalworking equipment, not shown in the accompanying illustrations, that should be mentioned and their principal uses described.

Double-action presses are of two types: one in which the outer ram, or blank holder, is cam actuated, and another in which it is actuated by toggle links.   These types are made in bench sizes and up to other sizes large enough to draw a complete turret top for an automobile.

The principal application of double-action presses is blanking and drawing, but they are also used for hot sizing and forging and for a number of other purposes where two related operations are necessary. In some cases they are used for redrawing purposes.   A sleeve is brought down by the outer ram around the shell to be redrawn, while a punch on the inner ram descends and pushes the shell through the redrawing die.   In this way the shell is centralized over the die before the operation begins.

Safety-bench Power Press.—This press has a transparent curtain guard in front of the die. Rods attached to the guard connect with the clutch mechanism in such a way that the press cannot be operated until the guard is down. The guard will not rise until the press stroke has been completed. If the operator accidentally places his hand under the guard, or if there is any other obstruction there, the press cannot be made to operate. The guard is actuated by such a light spring that the operator's hand cannot be injured by its force.

Arbor Press.—This press is operated by hand and is mounted on a bench. Its ram is either round or square, and at the rear is a toothed rack vertically meshed with an operating pinion to which is attached a hand lever for imparting motion to the ram. Its base and overhanging head which guides the ram are cast in one piece. On the bed is a circular disk which has four or more radial clearance slots of different widths. The disk can be revolved to locate any of the slots centrally under the ram.

This well-known press, although very simple, should not be passed without comment, because of its convenience and its many practical uses in the pressworking of metals. A toolroom is incomplete without one or more of these presses for making light press fits. Assembling departments use them for light work such as assembling, staking, pressing, or forming over the lugs that clamp metal parts together. The disk is removed for inserting special tools.

An arbor press is useful for very delicate operations in which the amount of pressure applied is important. The hand-operating lever is very sensitive to the touch, and the operator can instantly "feel" in the hand lever what is happening when the tools come in contact with the work.

Air-operated Arbor Presses.—These presses are built in two types. In one type, the air cylinder is vertically attached directly over the ram. In another type, the cylinder is vertically attached in the rear of the press frame, with a power-multiplying link attached from the cylinder piston across the head of the press and connected with the ram. The power multiplication is a ratio of 3 to 1.

The press capacities depend upon the air pressure and the diameter of the cylinder bore. A nonvariable air pressure is essential. Press capacities can be obtained from 500 lb. up to 60,000 lb.; the latter capacity is feasible if the press frame is sturdy enough to withstand it. These presses are used for assembling, broaching, piercing, key seating, grooving, straightening, press fitting, stamping, and a large variety of similar operations.

Pillar Press.—This type of press is similar in general design to the arch types except that it has straight columns. The face of the ram is provided with a dovetail slot from front to back. The slot is used

DRAWING PRESSES

Toggle Press   Hydraulic Deep Drawing Press   Hydraulic Shell Cupping and Drawing Press
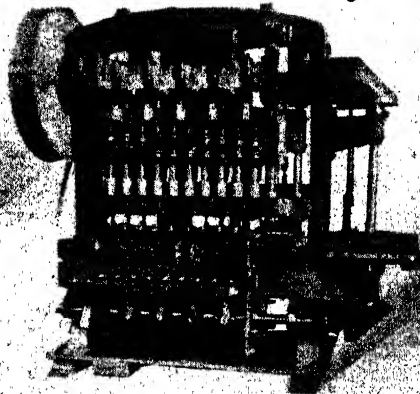
Horizontal Drawing Press   Multiple Eyelet Press

PLATE V.—Types of light and heavy drawing presses.

for attaching subpress dies which are designed to produce very accurate work. These presses are built plain and geared and with single- or double-action connections between the ram and crankshaft. Capacities run from 70 to 250 tons.

There are many special-purpose presses made for fabricating parts more speedily and economically than can be done on any type of standard commercial presses. There are also machines auxiliary to presswork, such as shell-trimming lathes, tube-forming and seaming machines, and machines for thread rolling, spinning, strip slitting, etc.

DRAWING PRESSES

Like high-speed presses described previously, drawing presses will be considered as a group without regard to frame construction. The arch press can be supplied with a long stroke for redrawing deep shells. It is built both single- and double-geared. Press strokes are from 6 in. for the smaller sizes up to 20 in. or more for the larger sizes.

Single-action straight-side presses can be had with a large opening in the bed to accommodate spring, rubber, or hydraulic drawing attachments or air cushions.

Toggle Presses.—Double-action toggle presses are capable of drawing to greater depths than the single-action machines fitted as described. The outer slide, which is actuated by toggle links, descends first and holds the blank to be drawn, from which action it takes the name "blank-holder slide." The punch, which is actuated by the main crank of the press, then descends. The punch ram operates through the outside slide and draws the shell to the proper depth. Toggle presses can be used for redrawing, in which case the slide centers the cup and the ram pushes the cup through the redrawing die. Perhaps the largest field for the toggle press is the manufacture of kitchenware.

Hydraulic Presses.—Hydraulic drawing presses involve a number of construction variations. Some have an external pumping unit connected to the press by suitable piping and valves and operated at the press operator's direction. Other machines are self-contained in that they have an integral pumping unit mounted on top of the press. Ram pressures of 5,000 tons or more can be secured. High-speed pumps give hydraulic presses operating speeds that are comparable with those of the larger sizes of mechanical presses.

Hydraulic presses have been recently adapted to coining and embossing. A 1,000-ton model will have a stroke of 15 in. and weigh 80,000 lb. Small hydraulic presses for clamping and riveting from both sides of work have two rams. They are built in sizes up to 15 tons.

Horizontal Draw Presses.—These machines are built in two types for redrawing cylindrical shells. Either the shell is pushed through the die, or cam knockouts and strippers are provided if the shell is

shouldered or requires bottom piercing.   Presses driven like a shaper head are used for drawing pencil bodies.   Crank-driven types redraw larger shells up to 3 in. in diameter by 8 in. deep.   Shells are fed into a chute, and a transfer slide transports them from the chute to the tools.   Multiple-station presses will take a first-operation shell and reduce its diameter in as many as seven redrawing operations.

Experience has shown that most metals will stand more redrawing operations, without annealing, if worked continuously while the shells are warm than when the operations are not continuous and the metal cools between draws.   This advantage has been recognized in the operation of eyelet and multiple-plunger types of drawing presses.

Multiple-plunger Eyelet Machines.—As many as 11 draws have been made by multiple-plunger eyelet machines.   The lighter types are cam driven; the heavier models, crank driven.   The plungers are vertical and in line and extend the entire length of the press bed.   Strip is fed to the first station where the blank is cut and shallow drawn. Work is transferred from station to station for redrawing operations by centralized gripping fingers at each station and attached within a reciprocating frame on the dies.   The shells are knocked out of the dies, lifted into the transfer slide, and engaged by the gripping fingers.

Rack-and-pinion Deep-drawing Presses.—Machines of this type are vertical presses and are built with 10 to 30 tons capacity.   The advantages are uniform speed for the ram throughout its entire working stroke, deep drawing, accurate adjustments for the length of stroke, quick return of the slide, and avoidance of damage to the machine or tools if the belt breaks.

These presses are employed for drawing either light or heavy materials by simply changing the gears that control the speed of the ram and punch.   The quick return of the ram is accomplished by a set of reversing driving belts similar to those used for a planer.   The applications of these machines are for long uniform redrawing operations of cylindrical shells in which a crank-driven press would be obviously impractical.

There are many other types of presses, but most of them are special and therefore of more limited use.   Unusual problems involving nonstandard stroke, speed, pressure, or feeding arrangement are best determined by consultation with press builders.

Selecting the Proper Press.—In selection of the proper size and style of press for a given kind of work, E. W. Bliss Company lists the following points to be considered:

1. The size and type of die required.
2. The amount of stroke necessary.

PLATE VI.—Automobile manufacture, "The Valley of the Giants," in the Chrysler plant, Highland Park, Mich. The die used for stamping two front fenders at one time is seen in the two-story machine located in the left foreground. (*Ewing Galloway.*)

3. The press pressure required for doing the work.

4. The distance above the bottom of the stroke where the pressure first occurs.

5. Any additional pressure required due to attachments, such as the blank holder, ironing wrinkles, or stretching the material in drawn work.

6. The method of feeding, the direction of feed, and the size of the sheet, blank, or work piece.

When the pressure occurs at or near the bottom of the stroke, with a comparatively short stroke, the tonnage given in the reference table is safe for a given size of crankshaft. At this point the crankshaft is under a bending load similar to a beam supported at its ends with the load concentrated at the center.

When the pressure occurs at quite a distance *above* the bottom of the stroke, or when the length of stroke is comparatively long, as in toggle-drawing presses, thereby increasing the effective crank arm, the load on the crankpin produces a torsional load on the crankshaft. This load on the crank bearing is limited by the gearing and the amount of torsion the crankshaft will safely take.

On some single-crank presses with a very long stroke, or on double-crank presses of great width or with a long stroke, and on all large single- and double-crank presses, "twin gearing," or a gear on each end of the crankshaft, is employed. This arrangement increases the gearing strength and torsional capacity of the crankshaft and, in the case of a wide double-crank press, reduces the torsional deflection of the crankshaft. However, under these conditions the load at the bottom of the stroke would still be governed by the figures given in the table. In all cases where twin gearing is used, the press would be operated by a friction clutch.

Capacities of Presses.—The strength of a single-crank press is determined by squaring the diameter of the crankshaft in inches, taken at its main bearings, and multiplying the result by $3\frac{1}{2}$ tons. This formula gives the conservative strength of a single crank in tons but only up to and including a 6-in. diameter shaft. It is advisable to select a press capacity in excess of the actual pressure required to do the work, at least 25 per cent higher. The formula given is for crankshafts having main bearings of equal diameters and located on each side of a single crank. The ultimate capacity is at the bottom of the crank stroke.

For double-crank presses the strengths are identical with those having a single crank up to 9-in. shaft diameters; above that diameter the double-crank presses exceed the strength of single-crank presses

rapidly as the shaft diameters increase. This increase is shown in the following reference table.

Crankshaft diameter, inches	Single-crank press, tons	Double-crank press, tons
6½	150	150
7	180	180
7½	215	215
8	255	255
9	345	345 ·
10	440	450
11	545	650
12	665	900
13	790	1,150
14	920	1,400
15	1,060	1,700
16	.....	2,000
16½	1,300	
17	.....	2,300
18	1,560	2,700
20	1,950	
22	2,380	
24	2,860	

The tonnage figures do not apply to the end-wheel type of presses which have an overhanging crankpin. For capacities of these presses, square the diameter of the crankpin, and multiply the result by 3 tons.

Crankshafts are forged from commercial billets of about 0.45 carbon content steel. For extra strength and continuous high speeds, chrome-nickel-molybdenum steel forgings are used.

By the following table of ultimate shearing strengths, it is possible to determine the pressure required for blanking a large variety of metals and other materials. The table is based on the use of flat-faced cutting members, but for a shearing cut, when the material does not exceed ¼ in. in thickness, use two-thirds of the tonnage given; and for any thickness exceeding ¼ in., use three-fourths of the table tonnage. Multiply the total cut length, or perimeter of the blank in inches, by the thickness of the material in inches, times the material tonnage. The result is the tons pressure required for shearing or blanking with a flat punch and die. If holes are pierced in the operation, their circumferences must also be added to the length of the blank outline.

Computing the Blanking Pressure.—A blank with a total cut edge 12 in. long is to be cut in a flat-faced punch and die. The material

ULTIMATE SHEARING STRENGTH OF MATERIALS
USING FLAT-FACED PUNCH AND DIE

Material	Tons per sq. in.	Material	Tons per sq. in.
Aluminum, cast..............	6	Paper, using hollow die......	1½
soft sheet................	7½	using flat punch..........	4¼
half-hard sheet............	9½	bristol flat punch........	2½
hard sheet................	12½	strawboard flat punch.....	1¾
Asbestos millboard..........	2	Silver....................	15
Brass, cast.................	18	Steel casting...............	30
soft sheet................	15	boiler plate..............	30
half-hard sheet...........	17½	angle iron...............	30
hard sheet................	20	cold-drawn rod..........	29
Bronze, gun metal..........	16	drill rod, not tempered....	40
phosphor..................	20	nickel about 3¼ per cent..	41
Copper, cast................	12½	nickel about 5 per cent....	42½
rolled....................	14	silicon...................	32½
Cupronickel.................	20	stainless.................	35
Duralumin, soft sheet........	15	0.10 carbon (soft)........	22½
treated...................	17½	0.25 carbon (mild).......	25
treated and cold rolled.....	20	0.50 carbon.............	35
Fiber, hard..................	12	0.75 carbon.............	40
Nickel silver, half-hard sheet..	16	1.00 carbon.............	42½
Iron, cast...................	12½	1.20 carbon not tempered..	47
2 per cent nickel..........	25	1.20 carbon tempered.....	95
wrought..................	20	hot........⅙ to ¼ strength of cold	
Lead.......................	2	Tin, cast.................	3
Leather, chrome.............	3½	rolled sheet..............	2½
oak......................	3½	sheet steel coated with tin..	25
rawhide..................	6½	Zinc, sand cast.............	7
Monel metal, cast...........	30	die cast..................	8
rolled sheet..............	32½	rolled sheet..............	9
		hard rolled..............	10

is 0.25 carbon steel, No. 24 U.S. gage (0.025 in. thick). What blanking pressure is required?

Solution: $12 \times 0.025 \times 25 = 7\frac{1}{2}$ tons.

Stripping Pressure.—It is often necessary to know the stripping tension on cutting punches, especially in large dies, so that the stripper plate can be designed of adequate strength to avoid buckling. Stripping pressure is one of the most deceiving requirements in the design of large blanking dies. Unless it is actually computed and definitely known, serious mistakes in stripper designs sometimes occur.

Stripping occurs at the critical moment when the blanked strip is carried up with the punches and suddenly hits underside the stripper plate.

Automotive body shops have adopted the following formula, which is also of value for finding stripper pressures in small dies. It determines the size and number of screws necessary for holding the stripper plate.

P = pressure required for stripping, in pounds.

L = length of the cut edge.

T = thickness of material strip.

Then $P = 3,500LT$.

Drawing Pressure.—The highest pressure that can occur in drawing is that which will rupture the shell. The formula for this condition is

$$P = \pi\, dtS,$$

in which P = pressure, in pounds.

　　　　d = diameter of the shell (outside diameter minus thickness).

　　　　t = thickness of material.

　　　　S = nominal ultimate tensile strength of the material.

The diameter of drawn cylindrical shells is the distance from the center line of one wall to the center line of the opposite wall.

Computing the Reduction Percentage of Drawn Shells.—In drawing a shell from a blank, the maximum reduction of the diameter should not exceed 50 per cent. However, when the press and tool conditions are good and the physical properties of the material is of high ductility, this limit can sometimes be considerably exceeded. Percentages of drawing reductions are understood to be as follows: The difference between an 8-in.-diameter blank and a 4-in.-diameter shell represents a 50 per cent reduction. The percentage of reduction between a 5-in.-diameter blank and a 3-in.-diameter shell is 40 per cent. The same relationships are similarly considered and computed between the diameters of redrawn shells. This subject is considered in detail under the chapter on Drawing Dies.

CHAPTER III

STAMPING AND FORMING MILD STEELS

A Knowledge of the Materials Available and Their Reaction under Given Working Conditions Constitutes a Basis for the Pressworking of Metals

S.A.E. Steel Specifications.—The principal compositions of commonly used ferrous and nonferrous metals have been classified by the Society of Automotive Engineers in collaboration with the mills.

The steels are designated by four or more consecutive numbers prefixed by the initials S.A.E. The first number in a specification indicates the class in which the steel belongs. Thus, figure 1 indicates carbon steel; 2, nickel steel; 3, nickel-chromium steel; 4, molybdenum steel; 5, chromium steel; 6, chromium-vanadium steel; 7, tungsten steel; and 9, silicon-manganese steel.

In alloyed steels, the second number usually indicates the percentage of the principal alloy. The last two or three numbers represent the carbon content in "points," or the hundredths of 1 per cent. Thus, a suitable deep-drawing steel may be specified S.A.E. 1010. The first 10 indicates an unalloyed carbon steel of high ductility; the last indicates a "10-point" carbon content.

Open-hearth Steel.—The grain direction in rolled steels and other sheet metals runs parallel with the edges of the sheet or strip, which is also the direction of rolling. In presswork where several square bends occur in random positions, some of the bends will be parallel with the grain, a condition that may cause bending fractures. Unless the radius of the bend exceeds the material thickness, the axis of the bend should be positioned across the grain at an angle of not less than 30 deg., the ideal position being 90 deg. However, sharp-cornered bends are often successfully made in the soft tempers of thin steels under about 0.0375 in. gage, without fractures.

Open-hearth steel is safely used for making square-cornered bends in any direction, regardless of the position of the bend; it is used for deep-drawing operations in which fractures are likely to occur because it has no appreciable grain direction. Deep-drawing open-hearth sheets have an Erichsen value of 8.2 mm. (0.323 in.).* For difficult

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* Erichsen values are for sheets 0.4 mm. (1/64 in.) in thickness, soft annealed.

drawing and forming operations "skin-rolled" steel can be furnished
by the supplier.

Mild Steel

Carbon, 0.05 to 0.15 per cent
Manganese, 0.20 to 0.50 per cent
Phosphorus, not over 0.04 per cent
Sulphur, not over 0.055 per cent
Tensile strength, 37,500 lb. per square inch
Elastic limit, 27,000 lb. per square inch
Elongation in 2 in., 40 per cent
Rockwell* hardness, B-35 to B-55
Weight, 0.283 lb. per cubic inch
Erichsen value,† 7.5 mm. (0.295 in.)

Nomenclature of Mild Steels.—Mild steels are those in which the
carbon content is either very small or practically absent. Eleven
tempers of mild steel are commonly used in press operations, namely:
annealed, dead soft, soft, bright annealed, $\frac{1}{4}$ hard, $\frac{1}{2}$ hard, $\frac{3}{4}$ hard,
hard, extra hard, spring hard, and extra spring hard. Beginning with
$\frac{1}{4}$ hard temper, each pass through the rolls reduces the thickness of
the sheet by one gage number. The word "pass" is usually omitted,
and the steel is known as 1 hard, 2 hard, etc. Steels are furnished
either in strips or in sheets. Strip is produced by the continuous
rolling process.

Cold-rolled Steel Strip for Deep Drawing.—Steel strip that is
continuously cold rolled has a decided advantage for deep drawing,
particularly from the standpoint of surface appearance of the finished
shell and in the actual drawing operation. The reason for this is due
to the reduction of cross section in the strip by the continuous-rolling
process. Strip may be rolled to 16 gage and then cold rolled to 18
or 22 gage, whereas sheet is cold rolled only one number. Strip
therefore presents a harder, stiffer, smoother surface than sheet.
The elastic limit of strip is, on the average, higher than sheet, even
with the same chemical content.

Strip steels have one drawback, however, which although not
serious may be annoying if one is unfamiliar with it. This is its
tendency to age-harden. This hardening, although hardly perceptible
by test, will worry the pressroom considerably if the reason for the
failure to produce properly formed and drawn work is unknown. The
remedy for the trouble is, of course, a normalizing heat treatment.

Steel Temper Difficulties in Drawing Operations.—Experience has
shown that a drawing die constructed for a material of a certain temper

* Details of the Rockwell hardness tester are given in Chap. V.
† Erichsen values are for sheets 0.4 mm. ($\frac{1}{64}$ in.) in thickness, soft annealed.

number will not produce a satisfactory drawn shell from steel even one temper harder. The shells from slightly harder steel will show wrinkles. Hard steels must have less drawing clearance than soft, so that the drawing strain on the blank, at the die entrance, is greater than the elastic limit of the material.

The troubles relative to wrinkles and die clearances relate mostly to large work, such as automotive parts, rather than to the ordinary small drawn part, but the same causes will always produce the same results irrespective of size. A slight difference in steel tempers can easily account for the difference between a few and many spoiled parts.

Stainless Steel.—The characteristics of chrome-nickel rust-resisting steel, otherwise known as "stainless steel," are resistance to corrosion, low heat conductivity, great strength, and ductility.

Chrome-nickel, "Stainless" Steel (Mild)
Tensile strength, 60,000 per square inch
Yield point, 45,000 per square inch
Elongation in 2 in., 60 per cent
Rockwell hardness, B-78
Erichsen* value, 9.5 mm. (0.374 in.)
Weight per cubic inch, 0.3033 lb.

The word "stainless" is a registered trade name which is applied to a specific make of steel. Theoretically, no one has a right to use the word stainless in connection with steel unless he is describing or using the steel licensed under the "stainless" patents.

There are as many different mixtures of chrome and chrome-nickel steels as there are carbon steels, and their relation, one to another, is about the same. The addition of nickel has about the same effect as it does in ordinary steels. It affords some resistance to corrosion and materially improves the physical or mechanical qualities.

It is characteristic of all stainless, or noncorrosive, steels that they must contain 11 per cent of chrome; they also require 18 per cent of chromium for each per cent of carbon.

Drawing Stainless Steel.—This material cannot be drawn so easily as ordinary mild steels. The labor cost of producing drawn parts is about twice that for ordinary steel. In drawing, it requires 25 per cent more power, and the dies last only about one-half as long.

It is necessary to anneal between drawing operations, sometimes to 1950°F. and at other times only to 1350°F., depending, of course, upon the severity of drawing operations. Before annealing, parts should be thoroughly sand-scoured so that every vestige of the lubricant used for drawing is removed. The lubricant, if left on the

* Erichsen values are for sheets 0.4 mm. (1/64 in.) in thickness, soft annealed.

shells through annealing, forms a gritty abrasive which is very destructive to dies.

After annealing, the parts are pickled in a 15 per cent solution of hydrochloric or muriatic acid and afterward in a 10 per cent solution of nitric acid and again thoroughly scoured with beach sand. The scouring is important and must not be slighted if best results are expected. Do not use sulphuric acid as a pickle or for cleaning.

Spinning Stainless Steel.—This operation requires about five times as much labor as is needed for spinning ordinary steel. Generally, drawn or spun parts should not be left overnight in an unannealed condition, for the work would be likely to fracture in the next operation. This precaution refers more particularly to "ironing" or severe drawing operations.

Polishing Stainless Steel.—About ten times as much labor is required to polish stainless steel as to polish ordinary steel. Usually there are two or three grinding operations, using Nos. 60, 120, and 200 grain abrasives. Opinions differ as to whether ordinary polishing rouge should be used or not. Rouge usually contains sulphur which is injurious to stainless steels.

As compensation for all these difficulties, stainless steel makes a beautiful, lasting piece of finished work which requires no polishing afterward. Light-gage sheets of stainless steel can be used to obtain the same stiffness given by other steels, because stainless steel is about 25 per cent stiffer than mild steels.

TABLE SHOWING THE PENETRATION DEPTHS FOR MILD STEEL IN PUNCHING OPERATIONS

(Using a flat-faced punch)

Thickness, inches.....	1	¾	⅝	½	⅜	⁵⁄₁₆	¼	³⁄₁₆
Penetration per cent..	0.25	0.31	0.34	0.37	0.44	0.47	0.50	0.56

Thickness, inches...........	⅛	³⁄₃₂	¹⁄₁₆	¹⁄₃₂				
Penetration per cent.........	0.62	0.67	0.75	0.87				

Lubricants for Drawing Steel.—Use a heavy oil, animal or mineral, thoroughly united with equal parts of black lead. A heavy plain grease mixed with about 10 per cent of white lead is also used successfully. For heavy steel shells, white lead may be used, thinned with kerosene to the consistency of paint. The drawing of steel requires heavy lubricants; for deep drawing, the consistency should be thickened. Small light steel shells can be drawn with lighter lubricants, such as lard oil or light greases.

Specific Gravity of Materials.—This subject is of more importance in the mass production of parts than we might be ready to admit. It tells us how many pieces, more or less, can be blanked from 1 lb. of material as compared with the material already in use. Of course, the difference in the material costs per pound also enters the picture.

If 20 parts are being blanked from 1 lb. of strip steel, the specific gravity of which is 7.83, and if possible to substitute vulcanized fiber, which has a specific gravity of only 1.41, we can obtain 111 pieces from 1 lb. of vulcanized fiber, or more than 5½ times as many pieces as from the strip steel. The result, of course, is obtained by dividing 7.83 by 1.41, which is 5.55, and 20 × 5.55 = 111. Tables that give the weights of materials per cubic inch can also be similarly used.

Specific gravity is a number that shows how many times lighter or heavier the weight of any material is when compared with an equal volume of pure water. The standard temperature of the water is 4°C. Since 1 cu. ft. of water weighs 62.428 lb. and there are 1,728 cu. in. contained in 1 cu. ft., then: $\dfrac{62.428}{1,728} = 0.0361$ lb., or the weight of 1 cu. in. of water. Therefore, if the specific gravity of any material is known, it follows that the weight of the material per cubic inch can be found by multiplying its specific gravity by 0.0361 lb. By this method, tables of cubic-inch weights can be greatly enlarged. For example: The specific gravity of cast iron is 7.15, and 0.0361 lb. × 7.15 = 0.258 lb., or the weight of cast iron per cubic inch. Conversely: dividing the cubic inch weight of any material by 0.0361 lb. gives the specific gravity.

Quick Computation for Pounds of Stock per 1,000 Blanks.—The area of strip occupied by 1 blank, multiplied by the thickness, gives the cubic inches used for 1 blank. If the required cubic inches are then multiplied by the pound weight of 1 cu. in., we have the weight for 1 blank, and multiplied again by 1,000 (set the decimal point three places toward the right) gives the weight of material required for 1,000 blanks. The area of strip occupied by 1 blank is found by multiplying the width of strip by the blanking-center distance.

CUBIC INCH WEIGHTS IN POUNDS OF VARIOUS MATERIALS

	Pounds
Aluminum bronze, sheet	0.2783
sheet	0.0980
Antimony	0.2422
Asbestos	0.1011
Bakelite	0.0446
Bismuth	0.3538
Brass (sheet)	0.3080

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Bronze phosphor (sheet)................................. 0.3180
Celluloid.............................................. 0.0487
Chromium.............................................. 0.2347
Copper (sheet)......................................... 0.3220
Cork.................................................. 0.0087
Dow Metal (magnesium)................................ 0.0643
Duralumin............................................. 0.1010
Ebony wood (dry)...................................... 0.0450
Fiber (vulcanized)..................................... 0.0510
German silver, or nickel silver.......................... 0.3160
Gold, cast hammered.................................. 0.6975
     U.S. coin......................................... 0.6209
Invar steel (36 per cent nickel)......................... 0.3010
Iridium................................................ 0.8094
Iron, cast............................................. 0.2580
     sheet............................................. 0.2780
     ferrosilicon........................................ 0.2530
     wrought.......................................... 0.2807
Lead.................................................. 0.4110
Leather............................................... 0.0341
Mercury............................................... 0.4910
Mica.................................................. 0.1011
Micarta............................................... 0.0446
Monel metal, rolled.................................... 0.3212
Nickel................................................ 0.3140
Nickel silver........................................... 0.3160
Paper................................................. 0.0336
Pewter................................................ 0.2703
Platinum, sheet........................................ 0.7776
     wire.............................................. 0.7595
Rubber, soft........................................... 0.0341
     hard, ebonite...................................... 0.0416
Silver................................................. 0.3890
Steel, crucible sheet................................... 0.2853
     machinery......................................... 0.2818
     rolled sheet....................................... 0.2833
     stainless.......................................... 0.3033
     tool.............................................. 0.2853
     2½ per cent silicon, transformer grade.............. 0.2680
Tin................................................... 0.2632
Tobin bronze.......................................... 0.3040
Tungsten.............................................. 0.6776
Vanadium............................................. 0.1986
Zinc, cast............................................. 0.2567
     rolled sheet....................................... 0.2600
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Cubic Inch Weights in Practice.—The table of material weights per cubic inch is used for several purposes besides those previously mentioned. A close approximation to the weight of a proposed casting can be figured from the given dimensions on a drawing, before the

pattern is made. The center of gravity and "balance" in machines can also be determined by this table. The material costs of tools, dies, and machines can be similarly ascertained.

In computing the weights of tool and machine parts, it is convenient to use the tables prepared by the Kropp Forge Company. These tables give the weights of cross-sectional shapes of steel 1 in. long, for commercial sizes, and it is necessary only to multiply this given weight by the length of the piece to find the total weight. The tables are based on the weight of steel at 0.2830 lb. per cubic inch.

For computing costs of tool steels, a table should be prepared giving the costs per cubic inch, including hardening, of all the different brands in use. After finding the number of cubic inches in a piece of tool steel, the total cost of the piece could then be found by simple multiplication.

Ductility Tests for Drawing and Forming.—A ductility test can be made either by trying the material in a previously made die that uses the same material thickness or by making a cheap temporary drawing die. Large die shops are usually equipped with commercial testing machines for ascertaining the ductility of sheet metals. These machines are made in several sizes and designs, and up to capacities for testing steel $\frac{1}{4}$ in. thick with 35,000 lb. pressure. The latter machines are motor driven. Practical tests for ductility are probably more reliable than using tables of Erichsen values.* With a testing machine, however, many samples from different sheets of the same material can be tested in order to obtain the average ductility.

Computing the Volume of Irregular Shapes.—Immerse the object in a suitable container of water having a known volume. Measure the increased depth of water, and compute the water volume again. The difference in the water volumes represents the volume of the object.

SPRING STEELS IN COMMON USE

Flat-spring Steel

Carbon, 0.70 to 0.80 per cent
Manganese, 0.30 to 0.50 per cent
Tensile strength, 200,000 lb. per square inch
Elastic limit, 165,000 lb. per square inch
Elongation in 2 in., 0
Rockwell hardness, C-42

Flat-spring steel is made from annealed and cleaned strip, cold rolled to size. It is heat-treated either before or after forming,

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* The Erichsen test and methods for determining the hardness and ductility of metals are discussed in Chap. V.

depending on the acuteness of the required bends. It is generally used for locks, clips, spring washers, and flat springs. It is preferable to bend it at right angles to the grain if possible.

Motor-spring Steel

Carbon, 0.80 to 0.90 per cent
Manganese, 0.30 to 0.50 per cent
Tensile strength, 250,000 lb. per square inch
Elastic limit, 225,000 lb. per square inch
Elongation in 2 in., 0
Rockwell hardness, C-46

Motor-spring steel is made from annealed and cleaned strip, cold rolled to size. It is heat-treated either before or after forming. If only the ends are to be bent, the temper can be drawn locally in hot lead. It is used for phonograph and other large motor springs.

Clock-spring Steel

Carbon, 0.90 to 1.05 per cent
Manganese, 0.30 to 0.40 per cent
Tensile strength, 270,000 lb. per square inch
Elastic limit, 250,000 lb. per square inch
Elongation in 2 in., 0
Rockwell hardness, C-53

Clock-spring steel is made from annealed and cleaned strip, cold rolled to size and heat-treated before any forming operations are performed. If it is necessary to bend the ends sharply, the temper can be drawn locally in hot lead. This steel is used for clock springs and brush-holder springs on electric motors and generators.

Watch-spring Steel

Carbon, 1.10 to 1.19 per cent
Manganese, 0.15 to 0.25 per cent
Tensile strength, 330,000 lb. per square inch
Elastic limit, 310,000 lb. per square inch
Elongation in 2 in., 0
Rockwell hardness, C-62

Watch-spring steel is made from annealed and cleaned strip, cold rolled to size and temper. It is heat-treated in the flat strip.

CHAPTER IV

STAMPING AND FORMING NONFERROUS METALS

The Principal Requirement in Selecting a Material Is That It Best Serve the
Purpose Intended

Introduction.—It is impossible here to enumerate all the nonferrous
metals and alloys used in stamping and forming operations. The
number of such materials is very large; only the ones most commonly
used will be discussed.

The fabricating characteristics of a material with which one is not
familiar can usually be estimated satisfactorily by comparing the
physical qualities of the unfamiliar material with those of a material
of known fabricating characteristics. Ductility tests will give some
general idea of the ability of a material to withstand bending and
drawing operations, but the most satisfactory way is actually to
perform some such operations and observe the behavior of the material.
In considering costs, the relative weights of the materials must be
taken into account, and this, of course, is also true if the weight of the
finished article is important.

Because no generally accepted system for designating the non-
ferrous metals and alloys has been devised, it is usually necessary to
refer to the chemical analysis. Generally speaking, a bronze is a
copper-base alloy in which the metal secondary in point of quantity
is tin. An alloy containing less than 5 per cent tin should not be
termed a bronze unless tin is the only metal present with the copper.

Specifications for Nonferrous Metals.—Standard specifications for
many nonferrous metals and alloys in various forms have been pub-
lished by the American Society for Testing Materials (A.S.T.M.).
These may be found in the current book of standards of that society.
The Society of Automotive Engineers (S.A.E.) have established
specifications for several nonferrous alloys. References to the specifi-
cations of these societies, and those of the Federal government, are
frequently used on engineers' drawings.

Aluminum.—Numerous aluminum alloys are available in the form
of sheet. The most commonly used designations for these materials
are as follows:

Alloy	Per cent of alloying elements; aluminum and normal impurities constitute remainder*								
	Copper	Silicon	Manganese	Magnesium	Zinc	Nickel	Chromium	Lead	Bismuth
2S									
3S	....	...	1.2						
4S	....	...	1.2	1.0					
17S	4.0	...	0.5	0.5					
A17S	2.5	...	...	0.3					
24S	4.6	...	0.6	1.5					
51S	....	1.0	...	0.6					
52S	....	...	...	2.5	...	...	0.25		
53S	....	0.7	...	1.3	...	...	0.25		
61S	0.25	0.6	...	1.0	...	...	0.25		

* This table and the one following are used by permission of the Aluminum Company of America.

The symbols used to designate the tempers of these alloys are

O = soft annealed,

¼H = ¼ hard,

½H = ½ hard,

¾H = ¾ hard,

 H = hard,

W = quenched (solution treatment only),

T = quenched and aged (solution treatment followed by precipitation),

RT = cold worked after heat-treatment.

Of the alloys listed, 17S, A17S, and 24S are heat-treatable alloys at ordinary room temperature and are, therefore, available in the "T," or heat-treated-and-aged, condition as well as in the annealed condition. Alloys 53S and 61S are also heat-treatable, but they are different from the first three in that complete aging does not occur at room temperature after quenching. This is a distinct advantage when difficult forming operations are to be imposed, because the forming can be carried out on material in the "W," or quenched condition, and then the formed article can be aged to the T condition to develop higher strength.

The mechanical properties of the most generally used aluminum alloys are as shown in the table on page 34.

Alclad Aluminum Alloys.—The name "Alclad" has been registered as a trade-mark by the Aluminum Company of America. It designates those alloyed products which have unusual resistance to corrosion. This property has been attained by using a surface layer of

TYPICAL MECHANICAL PROPERTIES OF WROUGHT-ALUMINUM ALLOYS

Alloy and temper	Tension				Hardness	Shear	Fatigue
	Yield strength (set = 0.2%), lb. per sq. in.	Ultimate strength, lb. per sq. in.	Elongation, per cent in 2 in.		Brinell 500 kg. 10 mm. ball	Shearing strength, lb. per sq. in.	Endurance limit, lb. per sq. in.
			Sheet specimen (1/16 in. thick)	Round specimen (1/2 in. diameter)			
2S-O	5,000	13,000	35	45	23	9,500	5,000
2S-¼H	13,000	15,000	12	25	28	10,000	6,000
2S-½H	14,000	17,000	9	20	32	11,000	7,000
2S-¾H	17,000	20,000	6	17	38	12,000	8,500
2S-H	21,000	24,000	5	15	44	13,000	8,500
3S-O	6,000	16,000	30	40	28	11,000	7,000
3S-¼H	15,000	18,000	10	20	35	12,000	8,000
3S-½H	18,000	21,000	8	16	40	14,000	9,000
3S-¾H	21,000	25,000	5	14	47	15,000	9,500
3S-H	25,000	29,000	4	10	55	16,000	10,000
4S-O	10,000	26,000	20	25	45	16,000	14,000
4S-¼H	22,000	31,000	10	17	52	17,000	14,500
4S-½H	27,000	34,000	9	12	63	18,000	15,000
4S-¾H	31,000	37,000	5	9	70	20,000	15,500
4S-H	34,000	40,000	5	6	77	21,000	16,000
17S-O	10,000	26,000	20	22	45	18,000	11,000
17S-T	37,000	60,000	20	22	100	36,000	15,000
17S-RT	47,000	65,000	13	..	110	38,000	
Alclad 17S-T	33,000	56,000	18	..	...	32,000	
Alclad 17S-RT	40,000	57,000	11	..	...	32,000	
A17S-O	8,000	22,000	24	27	38	15,000	
A17S-T	24,000	43,000	24	27	70	26,000	13,500
24S-O	10,000	26,000	20	22	42	18,000	12,000
24S-T	44,000	68,000	19	22	105	41,000	18,000
24S-RT	55,000	70,000	13	..	116	42,000	
Alclad 24S-T	41,000	62,000	18	..	...	40,000	
Alclad 24S-RT	50,000	66,000	11	..	...	41,000	
51S-O	6,000	16,000	30	35	28	11,000	6,500
51S-W	20,000	35,000	24	30	64	24,000	10,500
51S-T	40,000	48,000	14	16	95	30,000	10,500
52S-O	14,000	29,000	25	30	45	18,000	17,000
52S-¼H	26,000	34,000	12	18	62	20,000	18,000
52S-½H	29,000	37,000	10	14	67	21,000	19,000
52S-¾H	34,000	39,000	8	10	74	23,000	20,000
52S-H	36,000	41,000	7	8	85	24,000	20,500
53S-O	7,000	16,000	25	35	26	11,000	7,500
53S-W	20,000	33,000	22	30	65	20,000	10,000
53S-T	33,000	39,000	14	20	80	24,000	11,000
61S-O	8,000	18,000	22	..	30	12,500	7,500
61S-W	21,000	35,000	22	..	65	24,000	12,500
61S-T	39,000	45,000	12	..	95	30,000	12,500
61S-T8	47,000	52,000	10	..	98	32,000	

pure aluminum on both sides of a special base alloy for a core. The thickness of the surface layer is about 5½ per cent of the thickness of the sheet. Thus, a stiff sheet is produced which has all the corrosive resistance of aluminum plus the strength of the core. In pressworking of Alclad, the physical properties of the alloying core govern the

tooling conditions. In the commonly used thicknesses of Alclad, 17S-T and 24S-T sheet, the tensile strengths are approximately 10 per cent lower than those for uncoated alloys.

Lubricants for Drawing Aluminum.—Mineral oils or compound mineral oils are the lubricants most commonly used for drawing aluminum. Water-soluble drawing compounds are usually not so satisfactory. The lubricant should permit the blank to slip readily between the blank holder and die and also should provide the necessary lubrication to prevent scratching the work. It is extremely important that a suitable lubricant be used.

The lubricant should be evenly spread on both sides of the sheet. Oils, greases, compounds, etc., can be evenly applied on both sides by passing the material between a pair of rollers that have been previously coated. There are good machines on the market for lubricating sheet materials evenly on both sides. The strip passes through the rolls of the lubricator and then enters the dies in the press.

Drawing Aluminum Sheet.—The alloys most generally used for the production of drawn shapes are 2S, 3S, 4S, 52S, and 53S. The severity of the draw to be made determines the temper of the sheet selected. For severe draws annealed sheet should be used, but for less severe draws it may be possible to use $\frac{1}{2}$-hard, or even full-hard sheet to produce a stronger article. A part may be drawn from 53S in the annealed or quenched (W) temper and then heat-treated afterward to produce higher physical properties.

As in all drawing operations, the design of the tools used is very important in obtaining satisfactory results. Die radii ranging between four and fifteen times the thickness of the original sheet are usually satisfactory. The radius of the punch is generally held to a minimum of about four times the thickness of the original sheet. Sharp die radii cause greater resistance to the flow of the metal; whereas if the radii are too large, wrinkles are likely to occur. The size of the original blank should, in general, be as small as possible, because excess metal restricts the flow and increases drawing difficulties.

Aluminum lends itself more readily to extruding or spinning and compression operations than it does to stretching or expanding. It is therefore advisable to make redrawing operations of moderate reductions. Percentages for redrawing reductions are given in Chap. XXII. When there are radical differences in diameters on the same shell, it is good practice to draw the larger diameter first and then reduce the lower part of the shell to the smaller diameter in subsequent operations.

Cracks in bending are likely to start at the point of maximum tension which is at the outermost fiber. Fractures may occur opposite

sharp bends unless the bends are made with the axis positioned across the grain. If the radius of a bend is greater than twice the sheet thickness, bends may be made in any direction regardless of the grain lines. The bending qualities of most sheet metal have been considerably improved during the past ten years. Most sheet metals, and especially thin stock, can often be bent parallel with the grain successfully.

With cups, or shells of any size, where the depth of the first draw is less than the diameter, no trouble should be encountered if instructions regarding the drawing radii and lubricant have been followed. The dies should have plenty of clearance; and if the right temper of aluminum sheet is used for the first drawing, annealing should not be necessary between several subsequent draws.

Annealing Aluminum.—The melting point of aluminum is 1220°F. It is therefore annealed in an air furnace. Annealing in a muffle furnace is for the purpose of normalizing metals that have melting points above 1400 and up to 1800°F. A muffle furnace is used to prevent direct flame contact on the metal and to exclude noxious gases which are injurious. Small aluminum parts have been successfully annealed in boiling oils that have low boiling temperatures. Two such oils are linseed oil and turpentine. Metals that are annealed in boiling oils have the advantage of being free of scales.

Duralumin

Aluminum, 95 per cent
Copper, 3.5 to 4.0 per cent
Magnesium, 0.2 to 0.8 per cent
Manganese, 0.4 to 1.0 per cent
Silicon, under 0.6 per cent
Iron, under 0.6 per cent
Tensile strength, 55,000 lb. per square inch
Elastic limit, 32,000 lb. per square inch
Elongation in 2 in., 18 per cent
Brinell hardness, 50

Duralumin is a lightweight material and has been largely used in airplane work. It is symbolized under the 17S series of aluminum. It is the most widely used of all the heat-treatable aluminum alloys. However, in recent times, duralumin has been almost entirely superseded by 24S aluminum for airplane parts, because the 25 per cent higher yield strength of the latter alloy is translated directly into correspondingly superior performance. The higher physical properties of this alloy also make possible the use of Alclad sheet with a material gain in strength as well as resistance to corrosion, in comparison with 17S sheet.

Severe forming operations have been accomplished with the soft tempers, such as 17S-O and 24S-O, but the finished parts must always be heat-treated before assembly. If this is not done, both their physical properties and resistance to corrosion are definitely inferior.

In working duralumin the sheet is first heated in a salt bath or air furnace at 930°F. and then quenched in cold water. It is then rinsed in warm water. Every effort must be made to perform bending operations within 1 hr. after quenching; otherwise checks and cracks may appear. The hardness, or temper, is unimportant on flat work. Small parts that require several die operations can be kept in workable condition by storage at low temperatures. It is best to take these precautions; otherwise the cracks may show up after final assembly in the apparatus. If the sheets are large, means for flattening must be provided, as the salt bath distorts the sheet.

For duralumin rivets, either large or small, it is important that they be annealed at an exact temperature each hour and a routine established to collect those not used within the hour. On large-quantity production on some of the parts the same procedure may be found necessary. The specific gravity and weight per cubic inch is 3 per cent heavier than for sheet aluminum. The specific gravity is 2.80; the weight per cubic inch, 0.1010 lb.

Nickel Silver

Copper, 64 per cent
Nickel, 6.75 per cent
Manganese, 0.06 per cent
Iron, 0.02 per cent
Zinc, 29 per cent
Tensile strength, 54,000 lb. per square inch
Elastic limit, 26,000 lb. per square inch
Elongation in 2 in., 64 per cent
Rockwell hardness, B-21
Erichsen value* 11 mm. (0.433 in.)

This metal was formerly known as "German silver." It is an alloy of copper, nickel, and zinc; it is very ductile. It can be rolled, hammered, stamped, and drawn to a greater degree than most metals without showing fractures. In blanking, it shows a clean sheared edge with a minimum of burrs. It is hard, tough, and not easily corroded and possesses the valuable feature of being white. It can be softened by annealing at temperatures between 650 and 1200°F. It has a weight of 0.3160 lb. per cubic inch.

* Erichsen values are given for annealed samples 0.4 mm. ($\frac{1}{64}$ in.) in thickness.

Tobin Bronze.—*This alloy, originally a product of the American Brass Company, contains 59 per cent of copper and about 40 per cent of zinc; the residue is approximately 1 per cent of tin, lead, and iron combined.*

Tobin bronze, sometimes called "naval brass," is rolled in sheets and plates from $\frac{1}{16}$ in. up to 2 in. in thickness, and rods are drawn up to 7 in. in diameter. It is also drawn in rectangular bar sections and in seamless tubes of many sizes. Tobin bronze has high resistance to corrosion and for this reason is largely employed in marine constructions which are subject to the corrosive actions of salt air and water. Its tensile strength is slightly above 60,000 lb. per square inch, and its compressive strength is up to 180,000 lb. per square inch. Elongation is in 2-in. ranges from 25 per cent for hard tempers up to 50 per cent for soft tempers.

In bending and forming high tempers of Tobin bronze, care must be used when making square bends unless they are positioned at right angles, or nearly so, across the grain. The average grades of this alloy are likely to become "work hardened" during second and third drawing operations, and it will probably be found necessary to anneal the work after making two or more draws.

Because Tobin bronze fails to produce sparks from friction, it is a valuable alloy for powder plates and powder-mill equipment, tools, and machines. Its melting point is 1570°F.; a muffle furnace is usually necessary for annealing. The weight per cubic inch is 0.304 lb.; its specific gravity is 8.4.

Phosphor Bronze

Copper, 95.5 per cent
Phosphorus, 0.1 per cent
Tin, 4.4 per cent
Tensile strength, 50,000 lb. per square inch
Elastic limit, 27,000 lb. per square inch
Elongation in 2 in., $2\frac{1}{2}$ per cent
Rockwell hardness, B-28
Erichsen value,* 11.5 mm. (0.453 in.)

The average grades of phosphor bronze consist of 91 to 97 per cent of copper and 3 to 9 per cent of tin. There is also a trace of phosphorus which adds hardness. Its commercial forms are wire, bar, strip, and sheet. Phosphor bronze possesses high resistance to corrosion, together with great toughness, elasticity, and tensile

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* Erichsen values are given for annealed samples 0.4 mm. ($\frac{1}{64}$ in.) in thickness.

strength. There are four tempers: half hard, hard, extra hard, and spring hard. Its percentage of elongation in 2 in. is very low—less than 20 per cent for the most and only 1 per cent in some of the harder grades. It is therefore difficult to make satisfactory bends or drawn shells of this material. In bending operations, as with spring brass, the inside radius of the bend must be three or four times the thickness of the material, and the die must be arranged to bend the part farther than needed on account of an inevitable spring-back.

Remelting of phosphor bronze increases its strength. In phosphor-bronze bearings, zinc should never be present. The alloy for bearings consists of 80 per cent of copper, 8 per cent of tin, 10 per cent of lead, and 2 per cent of phosphor tin. The principal requirement of all alloyed metals is that they best serve the purposes for which they are used. The phosphor-bronze group is particularly well-adapted for switch springs and electrical wiper contacts. It is used largely for mechanical springs. For either electrical or mechanical springs, where a more ductile metal is required, nickel silver is recommended. The weight of phosphor bronze is 0.3180 lb. per cubic inch.

Cartridge Brass.—This metal is standard material with most firms for deep-drawing operations. It is a 70-30 mixture of copper and zinc. Admiralty metal is practically the same alloy, being 70 per cent of copper, 29 per cent of zinc, and 1 per cent of tin. Both these alloys are used in the manufacture of rifle ammunition cartridges. Naval brass is 62 per cent of copper, 37 per cent of zinc, and 1 per cent of tin; Muntz metal is 60 per cent of copper and 40 per cent of zinc. The Brinell hardness numbers for No. 12 Brown and Sharpe (0.0808 in.) gage should be between 49 and 69. The weight is 0.308 lb. per cubic inch.

High-tensile Brasses.—These alloys include delta metal, manganese bronze, and similar mixtures and are generally 60 per cent of copper and 39 per cent of zinc, with iron and manganese added. They are very similar in composition and physical properties to Tobin bronze. The weight per cubic inch is practically the same as for Tobin bronze, and the pressworking conditions are similar. High-tensile brasses are also alloyed with nickel in quantities of about 3 per cent, iron 2 per cent, copper 60 per cent, and zinc 34 per cent. This metal is more resistant to acids than either copper or brass. Its weight is 0.304 lb. per cubic inch.

Sheet-brass Tempers.—When brass sheets are passed through the mill rolls and reduced one Brown and Sharpe gage number, the material becomes ¼ harder. By this process, the following tempers are made:

Dead soft................................. Annealed
1... ¼ hard
2... ½ hard
3... ¾ hard
4... Hard
6... Extra hard
8... Spring hard
10.. Extra spring hard

Tolerances allowed are 0.00025 to 0.006 in. for Brown and Sharpe gage numbers from No. 38 to No. 0000, respectively.

Generally, ordinary brass is a copper-zinc alloy containing one-third zinc and two-thirds copper, but bronze is a copper and tin alloy containing about 10 per cent of tin and 90 per cent of copper. Gun metal contains 90 to 92 per cent of copper and 8 to 10 per cent of tin. Lead is frequently added in these mixtures to improve machining conditions, and both tin and zinc are used in the same alloys, so that we have a series of copper-tin-zinc alloys of multitudinous variety. In all cases, however, these useful alloys always contain more than 50 per cent of copper. The weight of brass sheet is 0.308 lb. per cubic inch.

Copper and zinc will unite naturally in producing brass. However, the highest zinc content is limited to 36 per cent; above that, brass is likely to become too granular for high tensile strength.

Copper Alloys.—Although almost every known metal has been added to copper as an alloy, the intention is not to discuss these mixtures here but to consider the pressworking characteristics of sheet metals. Copper alloys that are best known under a trade name are as follows:

	Copper	Zinc	Manganese	Tin
Gilding metal	95	5		
Tombac brass	91	9		
Tombac red brass	88	12		
Fourney's alloy	82.5	17.5		
Red brass	82	18		
Dutch metal	80	18	2	
Delotot's alloy	80	20		
Imitation gold leaf	78	22		
Cartridge brass	70	30		
Two-and-one brass	66	34		
Naval brass	62	37	..	1
Muntz metal	60	40		
Brazing solders	50	50		

All these brasses belong in the alpha class and are therefore ductile.

Copper Alloys and Color.—The color of rich low brass is an impor·tant feature in its use. Alloys between 82 and 88 per cent of copper show considerable differences in color after the metal has been cleaned and polished. These color variations have suggested the use of several alloys of only slightly different copper content for the purpose of producing an exact color. Most of such alloys are produced for jewelry manufacturers.

Clock Brass.—Copper 62.5 per cent, zinc 36 per cent, and lead 1.5 per cent constitute the usual composition of this material. Clock brass is used in a ½-hard temper for clock-movement frames, light gears, and similar parts. It takes a clean cut that leaves little or no burr. It will take a right-angle bend without showing fractures. It takes a good clean thread and is often used for flat springs that are bent or require tapped holes. When reduced 35 per cent in thickness by cold rolling, it becomes spring tempered. Its weight is 0.310 lb. per cubic inch.

Copper.—Copper has a tensile strength, rolled and annealed, of 32,700 lb. per square inch. Its elongation in 2 in. is 35 per cent; its weight, 0.322 lb. per cubic inch. Copper is both malleable and ductile. There are two varieties of commercial copper in general use: arsenical and electrolic. The latter, as its name implies, possesses high electrical conductivity. The arsenical grade contains only about ½ to 1 per cent of arsenic and usually only a trace.

In bending, forming, and drawing dies, pure copper easily takes the lead over all other sheet metals in freedom from cracks, fractures, and wrinkles. Copper "work hardens" slightly after two or more operations but anneals readily at comparatively low temperatures. The quenching tank should be as close to the annealing furnace as possible, because if the heat is too high, copper oxidizes rapidly upon exposure to the atmosphere. The melting point is 1981°F., and a muffle furnace is necessary for annealing.

Tinned Copper.—This material is extensively used for electrical connections, clips, solder lugs, etc., and in large sheets for washing-machine tubs, cooking utensils and similar parts. It can be purchased tinned on one side of the sheet or on both sides. On small clips, telephone or radio connectors, and for all electrical terminals, tinning is an aid in soldering on the wire connections. Tinned strips are therefore economical to use. Tinning makes no difference in press-working of the strips or piece.

Monel Metal

Nickel, 65 to 70 per cent
Copper, 30 to 35 per cent
Tensile strength, 80,000 lb. per square inch
Elastic limit, 67,000 lb. per square inch
Elongation in 2 in., 15 to 20 per cent
Rockwell hardness, B-84
Erichsen value,* 11.5 mm. (0.453 in.)
Some samples contain a small percentage of iron.

This is a natural mixture of nickel and copper with a small amount of iron. It is silver-white in color, takes an excellent polish, and is highly resistant to corrosion. Strangely enough, it is taken from the mines with its three ingredients proportioned correctly by nature and is so smelted and refined. It is rolled and drawn to the common commercial forms and is highly resistant to heat. Sheets are used for roofing, chemical tanks, and cooking utensils, also for valves and valve seats in resisting acids and high temperatures. Its pressworking properties are similar to those of Tobin bronze. Its weight per cubic inch is 0.3212 lb.

Monel Metal, Spring Hard

Nickel, 70 per cent
Copper, 27 per cent
Iron, 3 per cent
Tensile strength,135,000 lb. per square inch
Elastic limit, 80,000 lb. per square inch
Elongation in 2 in., 1 to 2 per cent
Rockwell hardness, over B-100

Magnesium Alloys.—The predominating metal in this alloy is magnesium, which has a silver-white appearance and is the lightest in weight of all known metals. Its specific gravity is 1.78, whereas that of aluminum is 2.71. Magnesium is therefore two-thirds as heavy as aluminum and about one-fifth the weight of brass or copper.

In Germany, more than 50 lb. of magnesium alloys, known as "Elektron," or "Magnewin," is used in each bombing-plane motor, usually for the crankcase, gear boxes, cylinder head, and pistons. Landing wheels are also made of it, and it ·has been proposed for propeller blades.

Magnesium alloys are available in cast ingots, forgings, extruded sections, sheet, and strip. They machine easily and smoothly and can be worked in press tools about the same as 2S $\frac{1}{4}$ hard sheet aluminum.

* Erichsen values are given for annealed samples 0.4 mm. ($\frac{1}{64}$ in.) in thickness.

The tensile strength of hard-rolled sheet is 36,000 to 43,000 lb. per square inch, and the weight per cubic inch is 0.0643 lb. In medium-soft tempers, however, the tensile strength falls to approximately 26,000 lb. per square inch.

Magnesium Alloy

Magnesium, 88 per cent
Aluminum, 12 per cent
Tensile strength, 50,000 lb. per square inch
Elongation in 2 in., 3 per cent
Rockwell hardness, B-42

Comparing Percentages of Elongation.—A comparison of the percentages of elongation in 2 in. of any metals, with the drawing properties of well-known metals, is a fairly reliable indication of the drawing properties for the metal compared unless the metal compared is highly granular, like zinc.

Grain Size Is the Measure of Softness in Brass.—"The degree of softness in brass can most accurately be expressed in terms of the actual average grain size. The grain size is specified in terms of the actual average diameter of the crystals expressed in thousandths of a millimeter."* The examination is made under a high-powered metallurgical microscope in a sample that has been carefully ground and polished and then etched with a solution of concentrated ammonium hydroxide and hydrogen peroxide.

The average grain size of wrought brass is approximately from 0.0004 to 0.0036 in. Cast brass, however, is much coarser in grain structure, individual grains being approximately between $\frac{1}{16}$ in. and possibly as large as $\frac{1}{4}$ in. Fine-grained brass is suitable for stamping and forming because the surface of the metal, even when stretched, does not become rough. Such material can readily be buffed and colored. If the grain structure is coarse, stretching and bending operations produce a rough surface on the brass which must be ground off if the material is to receive a highly polished finish. A medium grain size is recommended for severe cupping and drawing operations on heavier gages of metal, especially when the side walls are "pinched" during the drawing operation.

Weights of Sheet Metals per Square Foot.—Prepare a constant of your own for the weights of sheet metals per square foot 0.001 in. thick. Multiply this constant by the number of thousandths in the thickness wanted. If sheet copper $\frac{1}{8}$ in. thick weighs 5.79 lb. per square foot, then 5.79/125 = 0.04632 lb., which is the weight per

* Bridgeport Brass Company.

square foot for sheet copper 0.001 in. thick.   Therefore, a square foot of No. 10 Brown and Sharpe gage, 0.102 in. thick, weighs 0.04632 × 102, or 4.725 lb.   Only one constant is necessary for each material.

Gage Sizes Used for Sheet Metals.—Strip steel is usually rolled to B.W.G. sizes, and sheets to U.S. Standard gage, although some mills roll both strip and sheet to the latter gage.   Nonferrous sheets are rolled to Brown and Sharpe gage sizes, except zinc which uses a sheet zinc gage prepared by Matthiessen & Hegeler Zinc Co.   Nonmetallic sheets are usually specified in decimal thicknesses of the common fractions of an inch.   However, to avoid the confusion of the dozen or more gage sizes, it is advisable to specify all material thicknesses in decimal fractions.

Cupronickel

Copper, 81 per cent
Nickel, 18 per cent
Iron, 0.2 per cent
Manganese, 0.15 per cent
Sulphur, 0.04 per cent
Carbon, 0.03 per cent
Tensile strength, 52,000 lb. per square inch
Yield point, 23,000 lb. per square inch
Elongation in 2 in., 34 per cent
Rockwell hardness, B-36
Erichsen value,* 11 mm. (0.433 in.)
Weight per cubic inch, 0.3205 lb.

Iron, manganese, sulphur, and carbon are impurities and vary in quantity.   The nickel-copper alloys are among the most ductile of nonferrous alloys and probably the most ductile of any useful alloy. A mixture of 80 per cent of copper and 20 per cent of nickel can be cold rolled from $1\frac{1}{4}$ to 0.035 in. by successive operations without annealing.

Cupronickel is used for the jackets on bullets for army and navy small arms.   There are 10 operations, which are all done on a dial-fed press without annealing.   After the last operation, the jacket can be crushed in a vise without showing a fracture.   This feature alone makes it worth investigating as a substitute for parts that must have several annealings.   It should be particularly useful for hydrostatic work that is successively expanded from within.   Although annealing is not necessary for ordinary purposes, cupronickel sheets can be reduced from a yield point of 80,000 lb. per square inch, which is its usual "as received" condition, to approximately 20,000 lb. per square inch by heating 3 hr. at 1382°F.   At the same time, its elongation in 2 in. is changed from 6.5 per cent, as received, to 44 per cent.

* Erichsen values are given for annealed samples 0.4 mm. ($\frac{1}{64}$ in.) thickness.

The copper-nickel alloys range from 2 per cent of nickel up to monel metal with 70 per cent. The action of the nickel seems to be to strengthen the copper without reducing its ductility. The extreme ductility mentioned for the 80–20 mixture is not possible with any other mixture of nickel and copper.

Corronil

Nickel, 70 per cent
Copper, 26 per cent
Manganese, 4 per cent
Tensile strength, 80,000 lb. per square inch
Elastic limit, 54,000 lb. per square inch
Elongation in 2 in., 42 per cent
Rockwell hardness, B-42
Erichsen value,* 11.5 mm. (0.450 in.)
Weight per cubic inch, 0.3250 lb.

This material is an imported synthetic copper-nickel alloy of the "monel type." Its chief advantage over the natural monel is that its composition is always the same, whereas that of the natural monel varies somewhat.

Duplex Metal.—Many combinations of two metals are used in presswork. Plating is not always satisfactory, or for some reason is not desired, and resort is made to a duplex metal where one metal is welded, brazed, or soldered to another. The two metals are then rolled together to the desired thickness. So-called "filled gold" is one example. Gold and a base metal of brass or other metal are soldered together with brazing solder and then rolled into sheets. The thickness of each at the finish is proportional to the thickness of the slabs soldered together. Sometimes, tungsten or silver is brazed to steel for contact points or disks. The use of duplex metal for thermostatic uses is increasing. Silver-lined or silver-covered cups are also used but in small sizes. The precaution to be taken with this metal is to order the base metal soft annealed so that working it will not mar the surface of the softer metal too much. This applies, of course, to drawing operations. For disks it is sometimes desirable to specify a hard-rolled base.

Embossing Bronze

Copper, 95 per cent
Tin, 4 per cent
Zinc, 1 per cent

* Erichsen values are given for annealed samples 0.4 mm. (1/64 in.) in thickness.

This mixture is used for bronze coins. It takes a good impression and does not extrude under embossing pressure.

Everdur

Copper, 96 per cent
Silicon, 3 per cent
Manganese, 1 per cent
Tensile strength, 50,000 lb. per square inch
Elastic limit, 20,000 lb. per square inch
Elongation in 2 in., 50 per cent
Rockwell hardness, B-28
Erichsen value,* 11.5 mm. (0.450 in.)
Weight per cubic inch, 0.3205 lb.

Everdur is a copper alloy combining corrosion and acid resistance with high tensile strength and toughness. Its pressworking properties are very similar to those of mild steel. It can be hot forged readily in a press.

Manganese Copper

Copper, 93 per cent
Manganese, 7 per cent
Tensile strength, 50,000 lb. per square inch
Elastic limit, 24,000 lb. per square inch
Elongation in 2 in., 44 per cent
Rockwell hardness, B-28
Erichsen value,* 10.5 mm. (0.413 in.)
Weight per cubic inch, 0.3227 lb.

These mixtures are often erroneously referred to as "manganese bronze"; but as the copper-zinc-manganese and the copper-iron-manganese alloys are called by the same name, confusion is bound to result, especially where their physical properties are different. Manganese copper is ductile and can be readily drawn. It does not work-harden easily.

Manganin

Copper, 70 to 85 per cent
Nickel, 2 to 5 per cent
Manganese, 12 to 25 per cent
Tensile strength, 50,000 lb. per square inch
Elastic limit, 28,000 lb. per square inch
Elongation in 2 in., 40 per cent
Rockwell hardness, B-36
Weight per cubic inch, 0.2945 lb.

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* Erichsen values are given for annealed samples 0.4 mm. (¹⁄₆₄ in.) thickness.

A very malleable and ductile metal when annealed. Stiff enough for springs when cold rolled. In its soft state it is used for shunt wires in electrical instruments. Hard rolled, it is used for springs in instruments and automobile horns.

Pewter

Tin, 90 per cent
Antimony, 7 per cent
Bismuth, 1.5 per cent
Copper, 1.5 per cent
Weight per cubic inch, 0.2703 lb.

This metal has been used since Roman days for vases and dishes. Originally it was simply a mixture of 70 per cent of tin and 30 per cent of lead, but in modern times antimony, bismuth, and copper have been substituted for the lead. The analysis given above is for the so-called "best" pewter. It is used for high-quality articles and can be spun or drawn in dies. The shapes of the dies would, of course, be somewhat different from those employed for brass and copper, as pewter cannot be drawn so deeply as those metals in a single operation, and it is difficult to anneal except in an air furnace or boiling oils.

Tin Plate

Tensile strength, 50,000 lb. per square inch
Elastic limit, 24,000 lb. per square inch
Elongation in 2 in., 35 per cent
Rockwell hardness, B-37
Erichsen value,* 7.5 mm. (0.295 in.)
Weight per cubic inch, 0.2807 lb.

The base for tin plate is thin sheets of either iron or steel. The base is coated with tin, and, in some instances, a composition of tin-lead alloys is used. The coating is evenly applied by methods similar to those used in the hot process of galvanizing sheet iron. If the coatings are smooth and free of small breaks or holes, the finished product is quite impervious to corrosion.

The standard sheet is 14 by 20 in. The smallest is 10 by 14 in., and the largest 26 by 26 in. The most economical size for ordinary use is probably 20 by 28 in. The number of sheets per box is usually 112 or 225, depending on size. Almost any desired size of plate, between the dimensions given above, is carried in stock. Boxes of tin weigh from 80 to 471 lb. The trade name for different thicknesses of tin plate is as follows:

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* Erichsen values are given for annealed samples 0.4 mm. ($\frac{1}{64}$ in.) in thickness.

Trade term	80 lb.	85 lb.	90 lb.	95 lb.	100 lb.	1C
Decimal thickness	0.008	0.009	0.010	0.011	0.012	0.013
Weight per square foot	0.367	0.390	0.413	0.436	0.459	0.491

Trade term	1 × 1	IX	IXX	IXXX	IXXXX
Decimal thickness	0.014	0.015	0.016	0.018	0.020
Weight per square foot	0.588	0.619	0.712	0.803	0.895

Pure tin is not used for drawing to a depth much beyond one half the diameter, or the depth that can be drawn in a single operation. Obviously, it cannot be annealed in a furnace heat, and therefore an air furnace or oils of low boiling temperatures are used for normalizing.

There is, of course, a variation in the thickness of tin sheets, but they are manufactured within plus or minus 0.001 in. difference in thickness. The difference in some cases may be attributed to a little heavier coat of tin.

Terne Plate

Tensile strength, 24,000 lb. per square inch
Elastic limit, 8,000 lb. per square inch
Elongation in 2 in., 35 per cent
Brinell hardness, 40
Erichsen value,* 6.5 mm. (0.256 in.)
Weight per cubic inch, 0.2666 lb.

This material is similar to tin plate in every way except that the coating is: lead 75, tin 25 per cent. In color it is dull and lusterless. Heavier sheets are terne plated, then tinned. This plate works easily in dies; and when it is drawn, the lead content acts as a lubricant.

Nickel (German) Silver, Spring Hard

Copper, 55 per cent
Zinc, 27 per cent
Nickel, 18 per cent
Tensile strength, 113,000 lb. per square inch
Elastic limit, 60,000 lb. per square inch
Elongation in 2 in., 2 per cent
Rockwell hardness, B-98
Weight per cubic inch, 0.3160 lb.

Like the other nonferrous spring materials, nickel silver is reduced 60 per cent in thickness by rolling, in producing a spring temper. This metal takes a high polish and does not easily tarnish. In its hard

* Erichsen values are given for annealed samples 0.4 mm. (1/64 in.) in thickness

condition, it is used for the better class of flat springs, such as in electrical apparatus and in places where corrosion is likely to occur.

Phosphor Bronze, Spring Hard

Copper, 95 per cent
Tin, 5 per cent
Phosphorus, trace
Tensile strength, 98,000 lb. per square inch
Elastic limit, 50,000 lb. per square inch
Elongation in 2 in., 2.5 per cent
Rockwell hardness, B-93
Weight per cubic inch, 0.3216 lb.

Phosphor bronze is reduced 60 per cent by cold rolling to produce a spring temper. Very little phosphorus is present. In some cases it cannot be detected by an analysis of the finished sheet. This alloy is resistant to corrosion at normal temperatures and is used for springs where the surroundings tend to produce that condition. Bending axis should always be across, or diagonally across the grain. Bends with axis parallel to the grain will fracture even with round corners.

Red Brass, Spring Hard

Copper, 72 per cent
Zinc, 28 per cent
Tensile strength, 95,000 lb. per square inch
Elastic limit, 32,000 lb. per square inch
Rockwell hardness, B-90
Weight per cubic inch, 0.3110 lb.

This material is made also with copper 64 per cent and zinc 34 per cent and called "yellow spring brass." It is cold rolled from strip until it is reduced 60 per cent in thickness in producing spring-hard material. It is used for either coiled or flat springs within its capacity. The yellow alloy is sometimes called "high brass"; but as that term is also applied to the same mixture in its soft condition, when used for drawing purposes, it seems preferable to designate it as yellow spring brass. Both alloys have practically the same physical properties and press-working conditions. The preference for either one is based on color.

CHAPTER V

SPECIFICATIONS FOR ORDERING SHEET MATERIALS

A Discussion of Gage Sizes, Annealing, Testing, Lubrication, and Methods for Handling Raw Materials in the Press Room

Of equal importance with a knowledge of what materials are available for presswork is a knowledge of how to specify and order material and how to determine in some simple way whether or not the material meets the specifications and will serve the purposes for which it is ordered.

Specifications for Ordering.—If you will examine the files in the purchasing department of the firm you are connected with, you will be surprised at the amount of correspondence apparently necessary to this simple function. This mass of correspondence is caused by insufficient information, by lack of knowledge as to what materials are available, and by specifications that are impossible to fulfill or are unnecessarily severe. Such conditions delay the receipt of materials, when a little knowledge or forethought on the part of the one who specifies would avoid delay. The purchasing agent should not for the sake of a cheaper price modify the specifications without consulting with the one responsible for the original specification.

Very often we add unnecessary conditions to our order. The quantity ordered is also important. Another important point in ordering is to have in mind the extras charged for by the agent or manufacturer. Most mills set a minimum tonnage that they will roll at a base price; for quantities less than the specified minimum, an extra price is added. This extra price varies, but one mill gives it as follows.

On a quantity of 2,000 to 5,999 lb. the extra is $0.25 per 100 lb.; on 100 to 199 lb. the extra is $4.25 per 100 lb. The extra for cutting to special lengths runs up to $1.10 per 100 lb. For slitting material there is also an extra charge. On material 0.026 to 0.028 in. thick and over, there is no extra for sheet strip 16 in. wide. For strip 1½ in. wide there is an extra of $1.90 per 100 lb. This extra is much greater when the lengths are short. Pickling is also an extra; so is an "off-standard" carbon content in steel.

Superlatives or definite terms should be avoided in ordering. We should avoid specifying "perfectly flat" or "to exact width." There is no perfectly flat sheet or strip to exact width, without special and

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costly extra work. Such specifications are at times necessary; and when they are, it should be ascertained whether it is more economical to have the mill do the work or whether it can be done at some stage of the manufacturing operations more economically. The "camber," or edge straightness, of a sheet or strip must be considered, also the difference in thickness at the edge and center of a sheet, called "crowning." Tell the manufacturer for what purpose the metal is intended, so that he may understand that the purchaser knows what he is ordering and that his requirements are reasonably justifiable.

The standard tolerance on camber of a sheet or strip is ½ in. in 8 ft. The standard of flatness is ¼ in. rise from a flat surface in 8 ft. These figures are specifically for cold-rolled steel but are practically the same for hard and half-hard nonferrous metals.

When ordering steels, the order should state (1) weight required of each size, width in inches, and the thickness expressed in thousandths of an inch. Sheet steel is rolled to U.S. gage, and strip to Birmingham gage; (2) the permissible variation in both width and thickness and also whether the variation is over, under, or half over and half under the gage size; (3) the kind of edges. There are six variations of edges: (*a*) a round or square edge; (*b*) a natural round or square mill edge, rather uneven; (*c*) a square slit edge; (*d*) round edge, rolled; (*e*) square, rolled after slitting on wide widths and by finishing after slitting on narrow widths; (*f*) square rolled edge. For wide widths the mill edge is usually satisfactory. For blanking purposes the slit material is cheapest; but for parts where the outer edges are not cut away, a rolled square or round edge may be preferable; (4) temper; (5) the finish (whether bright, extra bright for nickel plating, tinned, hot or electro-galvanized or coppered); (6) whether the steel is wanted in coils or strip and, if the latter, in what lengths. If it is wanted in coils, the minimum diameter of the center hole should be given if the coil is to be mounted on special reels.

Ordering Leveled Materials.—It is well to remember that there is a difference between "leveling" a strip or sheet and "straightening" a strip or sheet. Many of us are in the habit of calling a strip leveler a straightening roll. It is not. A sheet of metal cannot be straightened unless it is stretched or squeezed beyond its elastic limit. When a sheet must be made practically flat, it is stretched. Usually leveling suffices, because a little rise in the finished part is not usually discernible. It is, however, good policy to order sheet materials leveled at the mill.

Avoiding Confusion in Gage Sizes.—There are about 14 different gage sizes used in the United States; and because of this, much con-

fusion results.   Some mills have even made slight alterations in the third and fourth decimals of U.S. Standard sheet-metal gage sizes, from No. 2 gage through to the end of the table.   Thus, the pounds weight per square foot of sheet steel, in the changed thicknesses, would figure in even thirty-seconds of a pound or in multiples of $\frac{1}{32}$.   For example: No. 20 gage was changed from 0.0375 to 0.0359 in., and the weight of 1 sq. ft. of sheet steel would then be 1.500 lb.   This change makes the table what it was originally intended to be, namely: a table of weights and not thicknesses.   The original base for this table was the weight of wrought iron per cubic inch, which is 0.2807 lb.; but as the demand for sheet steels increased, and the latter material weighs 0.2833 lb. per cubic inch, these mills reasoned that the table should be changed accordingly.   However, the surest and most satisfactory method of ordering sheet metals is to specify thicknesses in decimals.   The manufacturer can then translate into any gage he may happen to use in his mill, and there should be no controversy as to which particular gage was intended.

Next in importance to ordering the right thickness and width of material comes the question of ordering the right temper.   The tempers, in their order from soft to hard, are dead soft, soft, half-hard, hard, extra hard, and spring hard.

When it is thought necessary to specify the type or degree of annealing iron-base alloys, the following nomenclature should be used.

Full Annealing.—Iron-base alloys are heated above the critical temperature range, holding above that range for a proper period of time, followed by a slow cooling through the range.   This treatment produces a dead-soft metal which will bend back upon itself without fracture.   However, this metal would be too soft for most drawing purposes.

Process Annealing.—Iron-base alloys are heated to a temperature below or close to the lower limit of the critical temperature range, followed by cooling as desired.   This is a quick anneal and reduces hardness by one-half.

Roughly, the critical range for iron-base alloys, of 1 per cent carbon content, is between 1400 and 1600°F.   A diagram is plotted with the temperatures as ordinates and the carbon percentages as coordinates, according to Sauveur's "Metallography and Heat Treatment of Iron and Steel."

Patenting.—Iron-base alloys are heated above the critical temperature range, followed by a cooling to below that range, in air or molten lead maintained at a temperature of 700°F.   This should produce a good drawing sheet.

Spheroidizing.—Prolonged heating of iron-base alloys takes place at a temperature in the neighborhood of but generally slightly below the critical temperature range, followed by a slow cooling. This treatment produces a dead-soft, short-grained material.

Normalizing.—Iron-base alloys are heated above the critical temperature range, followed by cooling to below that range in air at ordinary temperature. This treatment relieves strains caused by work-hardening and restores it to its original state.

Tempering.—The material is reheated after hardening to a temperature below the critical temperature range, followed by any desired rate of cooling. This applies more particularly to higher carbon steels. Low-carbon steel, iron, and nonferrous metals are tempered by cold rolling.

Carbon Percentages in Tool Steels.—Carbon steels are sometimes referred to as "20-point carbon" or "30-point carbon," etc. This is commonly understood to mean that there are 20 or 30 parts of carbon content in 1 per cent of the entire volume of the metal. Thus, a 40-point carbon steel would be 0.40 per cent carbon content in $\frac{1}{100}$ of the entire volume, and a 100-point carbon steel means that 1 per cent of the entire volume is carbon.

Annealing Nonferrous Metals.—Heat to dull red—between 900 and 1100°F.—and quench immediately in water. Aluminum should be heated to 650°F. and air cooled. Zinc and similar metals do not require annealing. After severe working they are improved by immersion in boiling water or baking but not above 500°F.

When furnace annealing between drawing operations, a muffle furnace is used for those metals having melting points between 1400 and 1800°F. In a muffle furnace, the work is protected from direct flame contact and harmful gases.

Metals having melting points below 1400°F. can be annealed in an air furnace. However, it is seldom that sheet metals of the latter class require annealing, because most of them can be redrawn several times without it.

After furnace annealing drawn work, the resulting black scales can be removed by giving the work an "acid dip." This will prevent them from flaking off in the next drawing operation, thus interfering with the work by gathering around the drawing die. Particles of scales are very injurious to drawing dies.

Annealing Nickel-chrome (Stainless Steel).—This metal requires special processing when annealing. Stainless steel work-hardens readily, and it must be annealed with much care. After any drawing operation, or after any severe bending operation, the parts must be

annealed without delay.   If drawn parts are left unannealed over-
night, they are likely to show cracks during the next operation.   The
same thing is true when the parts are only partly annealed.

Where the drawing operation is severe, the parts should be scoured
with beach sand, and every particle of lubricant or scale removed.
Then heat to 1950°F.   After cooling, pickle in a solution of 15 per cent
hydrochloric or muriatic acid and then in a 10 per cent solution of
nitric acid.   After rinsing in water, scour again with beach sand, and
rinse again.   The scouring is important.   Sulphur is fatal to the struc-
ture of nichrome steel; do not use sulphuric acid for cleaning or rouge
containing sulphur for polishing.   A piece of polished nichrome sheet
placed in dilute sulphuric acid will not lose weight or bulk; its polish
will be just as bright; but the metal itself will be rotten and if dropped
on a metal surface will sound and react like sheet lead.

Testing for Hardness.—One of the simple rules of mathematics is:
"From two known factors, a third, or unknown, factor may be found."
The same truth applies to the working of plastic metals.   No one test
will answer the question as to whether a metal is or is not satisfactory
for the purpose for which it is intended.   A hardness test alone does
not indicate whether the metal is ductile or not; but by comparison
with other tests, it does tell whether or not the present sample is similar
to others that were satisfactory.   The worker of plastic metals is
usually interested in the drawing, stamping, or bending qualities of
metal—in other words, its "workability."

The workability of a metal, as far as its bending and drawing quali-
ties are concerned, depends upon its degree of hardness, its elastic
limit, and its structure.   This, of course, is merely a general statement.
The design of the die, clearance between the punch and die, and speed
of the press are also important factors in drawing metals.   There are
three common methods of hardness testing: the Brinell, the Rockwell,
and the Scleroscope.   The Brinell method of testing hardness is by
the indentation of a hardened-steel ball into the surface of the sample
to be tested.   The Rockwell method is somewhat similar in principle
to the Brinell method.   It uses a small steel ball or a diamond cone
and measures the depth of penetration instead of the diameter of the
indentation.   The Scleroscope method measures hardness by a com-
parison of the rebound of a diamond-tipped hammer dropping by
gravity from a fixed height.   The height of the rebound is indicated on
a graduated scale.   Naturally, none of these systems is accurate on
very thin strip resting upon an anvil of hardened steel.

"Rockwell" Hardness Tester.—For general hardness testing there
are two scales on the regular Rockwell tester, the B scale and the C

scale. The *B* scale is used for testing soft steel, brass, phosphor bronze, etc. It is the standard scale for testing such soft materials, and the reading is obtained by using the 100-kg. load applied on a $\frac{1}{16}$-in. ball penetrator which reads on the red-figured scales on the dial. For routine purposes, it is necessary only to specify the letter *B*, followed by the proper hardness number, and this in itself indicates that the 100-kg. load and a $\frac{1}{16}$-in. ball penetrator was used. For example: Rockwell hardness *B*-78.

For testing hardened steels, it is necessary to use a diamond penetrator, as the steel balls become flattened when testing hard materials. For this purpose, the "Brale," a sphericonical penetrator, is used. The load used with it is 150 kg., and this condition of testing is designated on the *C* scale. All hardened and heat-treated materials are tested on the *C* scale, and it is necessary only to specify the letter *C*, followed by the proper hardness number, and this indicates that the diamond Brale penetrator and a 150-kg. load were used. For example: Rockwell hardness *C*-52.

Ductility Testing.—The best way to determine whether or not a metal will draw is to draw it, and there are two ductility-testing machines in common use for that purpose. One is made by Olsen, and the other by Erichsen. Both employ essentially the same principle. The Olsen machine employs a half ball actuated by a hand wheel. Figures 1 to 5, inclusive, are cross-section views through the dies employed for testing sheet materials in the Olsen system. These five conditions cover all the necessary ductility tests in most cases. The faces of all the punches are ball shaped, or hemispherical, and each punch-and-die unit will interchange in the machines. The pressure necessary to draw a cup, together with the depth of the draw, is shown on two separate dials. The usual procedure is to read the dials when the cup has been drawn $\frac{1}{4}$ in. deep and again at the point of rupture. The point of rupture is indicated on its corresponding dial by a sudden deflection of the pointer. By comparing these data with tested samples of the same material, from the record of other work used in previously made drawing dies, a suitable selection of material, ductility, and temper is easily made.

The Erichsen machine is built somewhat on the micrometer principle. The piece to be tested (about $3\frac{1}{2}$ by $3\frac{1}{2}$ in.) is clamped firmly between the die and a holder. The thickness of the sample can then be read on a scale. After the thickness has been ascertained, the holder is moved back about 0.020 in., a distance sufficient to give the test piece a certain amount of clearance. The holder is then secured in position by two wing screws. Next, the punch is advanced into the

sample. The operator watches the results in a mirror until the moment of fracture occurs, when the depth of the draw is read on a scale. Fracture takes place when it is possible to see light through the bulged dome of the drawn cups, shown in Figs. 6 to 10, inclusive. The speed at which the punch is advanced does not affect the test values, except when testing zinc.

The Olsen ductility test takes into account the power necessary to rupture a sample, but the Erichsen registers only the depth of the drawn cup at the moment of rupture. The depth of the draw is roughly proportioned to the thickness of the sheet; for instance, a good sample of copper 0.031 in. thick should draw a cup 0.455 in. deep, and
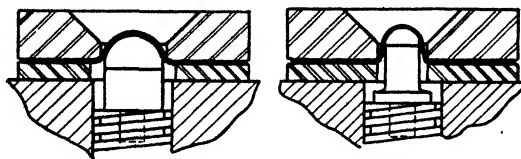

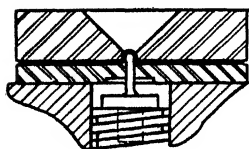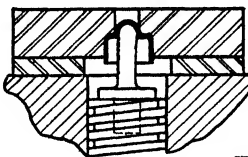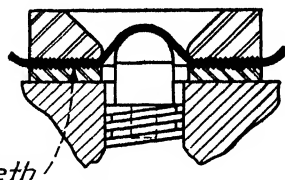
FIG. 1.   FIG. 2.

FIG. 3.   FIG. 4.   FIG. 5.

FIGS. 1 TO 5.—Various cupping dies used in the Olsen system for making ductility tests. The different diameters of punches are for testing samples of different widths, thicknesses, and depths. Fig. 4 is for testing cartridge shells, and Fig. 5 is for wires.

the same material 0.0625 in. thick would draw about 0.535 in. deep, using the same diameter of blank. For determining the softness of a cup after annealing, a smaller die is used, together with a punch long enough to bulge the bottom of the cup.

Probably the best method of utilizing either the Olsen or the Erichsen testing machines is to plot the results of tests on cross-section paper. With the Erichsen machine, the ordinate or vertical spaces should show the depth of impression, and the abscissa, or horizontal spaces, should show the thickness of the test sheet. A line drawn through the different plottings gives a curved line; but if the logarithm of the sheet thickness is used for the abscissa, instead of the sheet thickness itself, a straight line will result.

There are two reasons for testing sheet material; one is to measure its ductility, and the other is to determine what size of press shall be used. Neither the Olsen nor the Erichsen testing machine is of assist-

ance in assigning the job to a press, because with the press we have foot-pounds-velocity-area and thickness to contend with. Some die engineers use the elastic limit of the material as a guide for press capacity, but here again there is no practical relation between the two.
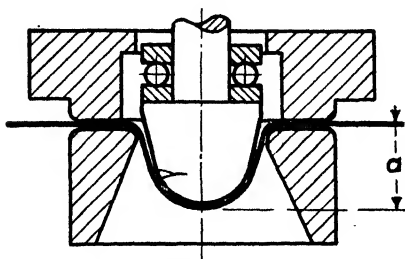

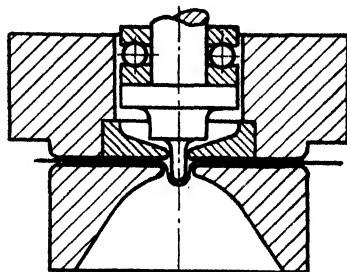FIG. 6.—Standard tool for testing metal sheets.

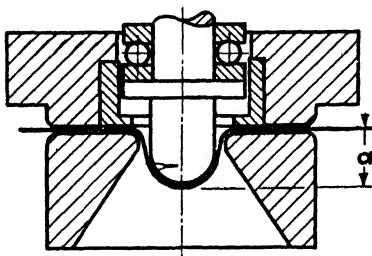FIG. 7.—Extra tool for testing strips of $\frac{5}{16}$-in. width.

FIG. 8.—Extra tool for testing strips of 1-in. width and over.
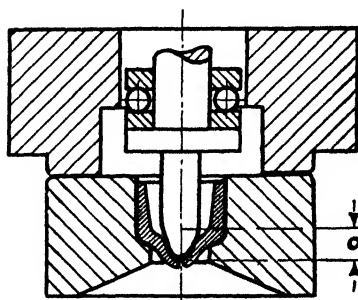
FIG. 9.—Extra tool for testing cartridge cups.
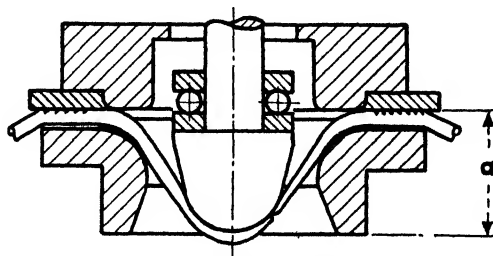
FIG. 10.—Standard tool with special die and holder for testing wires 1 to 6 mm. in diameter.

FIGS. 6 TO 10.—Designs of testing punches used for determining the Erichsen values of soft annealed samples of sheet metals and wires. Erichsen tests show the degree of anneal in the material, and are therefore largely qualitative tests.

The most accurate test by which to predetermine the press pressure for heavy drawing, swaging, or cold sizing operations is to make the first samples with the die set up in a hydraulic press which has a gage

that shows the tons of pressure used. From this test, the proper size of the press to run the job can be determined.

Lubricating the Material Strip.—That some press tools may perform their work satisfactorily for a time, without lubricating the strip, is the exception rather than the rule. The tool will stand up better, require less grinding, and therefore last longer, when the strip is properly lubricated. Animal, mineral, and vegetable oils, antifriction compounds, tallow, grease, water, soap, and various commercial compositions are used on the stock for easing the action on the work material and wear on the cutting or drawing members of the die. A lubricant is used in this connection with the blanking or drawing of sheet metals, for the same reason as used in a bearing, to prevent metal on metal contact between moving parts. Lubricants tend to prevent scratches in the work in passing over dies and under stripper plates and blank holders.

The lubricant used must have film strength strong enough to prevent metal-to-metal contact and to prevent picking up small particles of the cut metal. Aside from the heat generated by rubbing friction, there is also the heat generated by the plastic deformation of the metal being worked. It is essential that the lubricating film be not thinned down enough to allow metal-to-metal rubbing at high temperatures. Other properties desirable in a lubricant are viscosity, adhesiveness, spreading qualities, noncorrosiveness, odorlessness, resistance to climatic changes, and ease of cleaning. Needless to say, it must not injure the machine and work or affect the operator adversely.

Lubricants for Drawing Steel.—A heavy animal or mineral oil, thoroughly mixed with equal parts of black lead or graphite, is a lubricant often used. Sometimes a heavy grease mixed with about 10 per cent of white lead may be used, thinned with lubricating oil to the consistency of thick paint. The drawing of steel requires a heavy lubricant; and for deep drawing, the consistency should be thickened. Small, light steel shells can be drawn with a lighter lubricant, as lard oil or light greases.

In a high-speed pinching tool, if the stock lubrication is wrong, the punches will heat up to the point of drawing the temper of some of the smaller punches. In such cases, lard oil is the remedy; it has the property of cooling metal parts in action; although it is expensive, the use of a cheap substitute may prove false economy.

Lubricants for Drawing Brass and Copper.—Soaped water is extensively used. Fuller's soap disolved in hot water and used while hot is recommended. Soap containing resin, lye, potash, or alkali should be avoided. Soaped water made from Ivory soap chips and hot water

used while warm is in common use. The consistency of the soaped water should be heavy for thick, deep-drawn shells and proportionally lighter for small work.

Lubricants for Punching Brass and Copper.—Use lard oil or fish oil, thinned by the addition of 10 per cent kerosene.

Lubricants for Drawing Zinc.—Soaped hot water is best, used as hot as possible. A cheap grade of Vaseline may be used for both zinc and aluminum. Zinc is sometimes worked with warm kerosene, the warmer the better.

Lubricants for Drawing Aluminum.—Mineral oils or compounded mineral oils are recommended. Water-soluble drawing compounds are not so satisfactory. The lubricant should be evenly spread on both sides of the sheet. Aluminum cannot be successfully stretched without lubrication. For machining or punching aluminum, kerosene is used.

Applying Lubricants Both Sides of Strips.—If the lubricating solution is thin, as it is for blanking dies, the strips are passed through a tank that contains the mixture. If of a heavy nature, for drawing dies, heavy oils, greases, compounds, etc., both sides of the strip can be evenly coated with the mixture by passing the strip between a pair of rollers that have been previously coated.

There are good commercial machines on the market for evenly lubricating sheet materials on both sides. The strip passes through the rolls in the lubricator before entering the dies in the press.

HANDLING DIES AND RAW MATERIALS IN THE PRESSROOM

Saving Time in Handling Dies.—In manufacturing plants where considerable quantities of sheet-metal parts are blanked and formed in dies, the toolroom and press departments must necessarily be located near together. Dies need frequent grindings, changes, and repairs; some dies are very large, heavy, and difficult to handle. Some plants maintain a tool-repair shop in the pressroom. This saves considerable time and expense in handling dies unnecessarily and especially when the main tool shop is too far away or on a different-floor level.

Shop and Factory Layout.—A general shop and factory layout involves only one important consideration: the ease and convenience in handling of tools, products, and portable equipment between all departments.

The plan for an easy interchange of products and partial assemblies between manufacturing departments should rule out the frequent use of elevators between floors. If this cannot be done, then the depart-

ments involved should be moved nearer together and on the same floor
level.   Large presses must be mounted on concrete foundations, and
the pressroom for these machines is usually located either on the ground
level or in a basement.   Small presses can be set up and used on wood
floors, but presses larger than No. 4 require concrete floors or extra
foundations to take the weight.

Next comes the best arrangement for product delivery from
machine to machine and between benches, in each department.   If
circularly revolving tables are best for the rapid assembly of small
apparatus, the tables should be installed.   If belt conveyors are best
for moving work between machines or along benches, their installation
should not be omitted.   For transporting heavy parts, roller conveyors
are favored by most manufacturers.   Roller conveyors are commercial
and can be purchased in various widths and lengths much more
cheaply than they can be made.

There is a large variety of interdepartmental trucks on the market;
these can raise or lower heavy loads automatically.   With such trucks,
large heavy dies can be moved from the press on a level with the bolster
plate on which the die is used.   The die is then transported on the
truck and unloaded on a toolroom repair bench, at bench level.

There are portable cranes for moving heavy parts and assemblies
and overhead continuous-chain conveyors.   An overhead monorail
system through the shop affords cheap and convenient transportation
for certain tools and shapes of work.   The monorail idea was originally
borrowed from the meat-packing industries.   It was the manufacturers
of heavy metal apparatus who first developed it for light manufacturing
shops.   The latter shops have improved the monorail trolley to where
hand and electric hoists are attached, platforms used for conveying flat
stock, containers provided for small parts, and chain drives for passing
along the trolley load to assembling lines.

The cost of sheet and strip and of handling them to and from the
punch press plus the cost of scrap disposal is often greater than the
actual expense of press fabrication.   This would indicate that a profit-
able field exists which may be a more lucrative one than to invent
further improvements in dies and presses.   It is a condition that points
out the needs for better methods in handling of raw materials, scrap,
heavy dies, and the finished product.   In other words, the speed of
press operations seems to have improved more rapidly than the means
for feeding them with raw materials.

Handling Coiled Strip Stock.—Coils are usually shipped from the
mill and handled in the pressroom, laid horizontally on strong wooden
pallets, as illustrated in Fig. 11.   A chain sling is spread under the

pallet ends, and the load is hoisted after attaching the chain to an overhead crane. Each load may weigh from 1 to 3 tons.

The pallets and coils are hoisted from the stocking section and brought into line with one of several terminals in a monorail system that leads to the various presses. After the load is attached to the
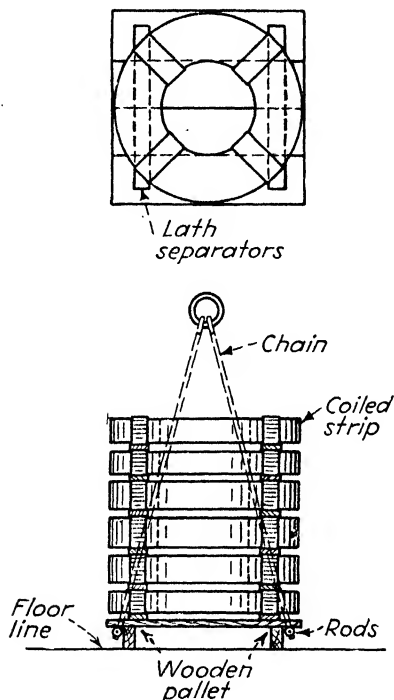

Fɪɢ. 11.—Coils of strip stock are hoisted on wooden pallets with a chain sling and crane hook, and are then transported.

trolley on a monorail, it can be weighed, if necessary, on a scale section in the track, or rolled on to a freight-elevator track for distribution on other floors. The load is lowered at the press, either on the platform of a portable elevator truck placed under it or by using a collapsible truck. When a monorail system is too expensive to install, small lots of coils are transported on hand trucks.

CHAPTER VI

PRESSWORKING NONMETALLIC MATERIALS

Details of Dies for These Materials Must Be Constructed Differently from Those for Working Metals

Introduction.—Many nonmetallic materials can be fabricated in press tools, for example, rawhide, leather, hard and soft rubber, cork rubber, celluloid, fiber, Fabroid, pressboard, asbestos millboard, Phenol and Micarta Plate, Durez and Bakelite sheets, mica, Empire Cloth, and felt.

The punch clearance in dies and the proper design of die details in order to avoid dust and chips that arise from some nonmetallic materials, which may choke the shedders and cause them to become inactive, and the handling of heated materials in dies are just a few of the problems encountered. Of the many nonmetallic materials used on the punch press, some of them are used only in the flat (blanking), whereas others can be drawn into cups.

Fiber.—Several varieties of fiber are worked in press tools: horn, red, white, and black. Of these, horn is the toughest, and black the most brittle. In thick sheets the horn varieties blanks best; the black is least satisfactory. If a smooth-cut edge is required, one or more shaving operations are necessary, depending upon the thickness. Thin fiber may be formed when dampened slightly, preferably by dipping in hot water or heating in a steam box. Electric lamp sockets and switches have an insulating lining of what is called "black fiber." This material can be obtained in tubes and sheets and can be drawn in dies, after moistening, in practically the same way as metals are drawn.

Horn fiber is tough and can be drawn and reduced, but unfortunately it fails to retain its shape after it dries. For that reason it is not practical to draw fiber, or dampened paper, into the receptacle for which it is intended for a lining. The weight of fiber per cubic inch is 0.051 lb.

Cutting Blanks from Sheet Mica.—Mica is a natural mineral of many qualities and colors. It is composed of thin layers the unit thickness of which is probably unknown. Mica has been subdivided into thicknesses of 0.00025 in., and no doubt it might be further subdivided if a method were known.

Mica sheets are highly resilient; when cutting blanks from it, a spring shedder blank support is necessary within the die opening to prevent undue deflection of the work. However, there are other difficulties to overcome. In cutting mica, a fine granular dust of high abrasive properties appears within the edges of the cut. These particles are very small; they will crowd in between the shedder edge and
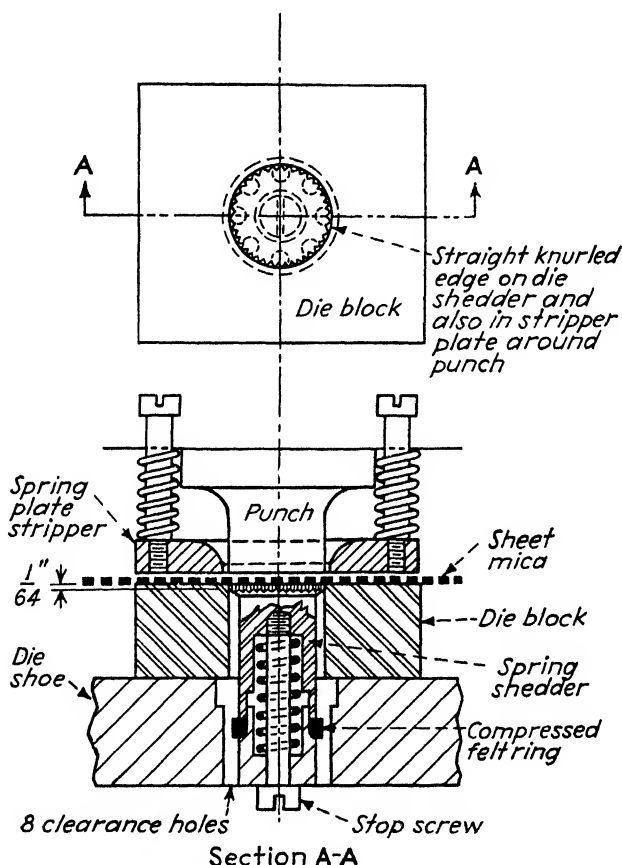

Section A-A

Fig. 12.—A blanking die used for cutting sheet mica.

die walls and finally choke the action of the springs. This trouble occurs even though the shedder is perfectly ground and lapped to fit the die. Some shops have attempted to prevent this trouble by dipping the sheet in turpentine before blanking. It was thought that this procedure might coagulate the dust particles and thus render them harmless; however, the results have not been satisfactory.

In Fig. 12 is a special design for a shedder that overcomes these troubles. The face edge of the shedder pad is only $\frac{1}{64}$ in. thick and is relieved by an open chamber around the shedder body which extends down into the die shoe. Clearance holes for dust lead away from the chamber through the shoe. The thin top edge of the shedder is straight knurled on its circumference; it is then hardened and ground to a free fit within the die. The knurling is shown exaggerated in the sketch to show the principle. This design provides ample clearance spaces and holes for the dust to fall through. A compressed felt ring prevents dust from entering the spring chamber. Using an air blast over the die to remove the dust is certainly not a "safety first" factor; fine particles of mica dust floating in the air are very injurious to health.

Care must be used in adjusting the press ram to allow the punch to enter the die just enough to produce a clean-cut blank. The shedder is removed when grinding the die, and surface adjustment is maintained either by providing the shedder with a stop screw underneath the die shoe or by shimming up the die block. Compounds of mica, such as Micanite, Megohmit, Megotale, flexible mica cloth, and mica paper, are blanked in dies of this design. An ordinary compound die for piercing and blanking sheet mica is shown in Fig. 323. The weight of mica per cubic inch is 0.1011 lb.

Vulcanized Sheet Fiber.—This material is sometimes called "hard fiber"; it is a composition of paper pulp saturated with a solution of zinc chloride. It is pressed into homogeneous forms under heavy hydraulic pressure, soaked in water to withdraw its soluble materials, and then dried in ovens. In hardness it resembles horn; it can be planed, sawed, sanded, or polished, the way very hard woods can. It is furnished in sheets, round rods, or tubes of many sizes and in several colors, black, red, and gray predominating. The specific gravity is about 1.4, and its weight per cubic inch is 0.051 lb.

Hard fiber can be pierced, blanked, or embossed without heating. Thin fiber parts, under $\frac{1}{64}$ in., can be formed and drawn with large radial bends at ordinary shop temperatures, but usually the material must be warmed slightly. Of such parts are the linings used in incandescent lamp sockets. Soft varieties are used in producing artificial leather and similar pliable compositions. Fibers are all nonconductors of heat, and all varieties are largely used for electrical insulations.

However, after piercing and blanking fibers, the piece changes in size slightly; it will contract in high dry temperatures and expand in low or damp temperatures. It is common practice to make certain die allowances for these changes in order to obtain accurate blanks and hole sizes, depending, of course, upon the temperature of the fiber when

blanked. The allowance for contraction is 0.0005 in., which is added to the size required for each $\frac{1}{16}$ in. thickness of the strip. *Examples:* for $\frac{1}{16}$ in. thickness the die for a 1,000-in.-diameter blank is made 1.0005 in. For $\frac{1}{8}$ in. thickness the die opening is 1.001 in. in diameter; for $\frac{5}{16}$ in. thickness, 1.0025 in. in diameter; etc. Over-all punch clearance should be about 10 per cent of the material thickness.

It cannot be emphasized too strongly that, contrary to what we may think, when a nonmetallic blank of the materials under discussion contracts, small holes far within the blank *decrease* in diameter. In using shrinkage allowances in blanking and piercing dies, this fact must be considered for accurate results. The final success of the tool may depend upon adherence to these rules. It is usually not necessary to make shrinkage allowances for distances between hole centers, unless the work is very long and narrow and close tolerances are specified.

Vulcanized Sheet Rubber.—This material is best known by the name "hard rubber" but is sometimes called "ebonite." The specific gravity is 1.154, and its weight per cubic inch is 0.0416 lb. After softening hard rubber by heating, it can be shaped or molded in various forms. Electrical industries use large quantities of hard rubber for insulating purposes, such as switch handles, plates between contact springs, and manually operated telephone spring-jack mounting strips. It can be sawed, milled, drilled, reamed, or pierced and blanked in dies. If machining cuts are taken too rapidly, the heat so generated may distort the work. The large sulphur content in hard rubber rapidly dulls the edges of cutting tools.

For piercing and blanking, the strip must first be heated on a plate mounted in a hooded gas oven. The heat is controlled so as continuously to soften the material just enough to prevent the punches from cracking the blanks. Blanks made by this method will contract in size when cooling, and the following shrinkage allowances, for accurate work, must be made. These allowances have been determined by experiment and practice.

When the heated strip is $\frac{1}{32}$ in. thick or less, the die opening is made $\frac{1}{27}$ larger than the diameter of the blank required. For stock more than $\frac{1}{32}$ in. thick, add 0.0015 in. to the diameter determined for $\frac{1}{32}$-in. thickness, for each $\frac{1}{64}$ in. of increased thickness above $\frac{1}{32}$ in. *Examples:* If a 0.540-in.-diameter blank is required from stock $\frac{1}{32}$ in. thick, then $\frac{1}{27}$ of 0.540 in. is 0.020 in., and 0.540 in. plus 0.020 in. is 0.560 in., the required diameter of the die opening. For a 0.540-in.-diameter blank in $\frac{1}{16}$-in. stock, we have 0.560 in., plus (2 $\times$ 0.0015 in.) or 0.563-in. diameter for the die opening. Since the diameters of pierced holes, which are located more than their diameter from the edge

of the blank, *decrease* when the blank shrinks, the same allowances must also be added to the diameters of the piercing punches.

Dielectric Plate Materials.—Micarta, Durez, Bakelite, Phenol Fiber, and similar compositions are heat-treated before blanking, as described for vulcanized sheet rubber but with slightly changed shrinkage allowances. Irrespective of the material thicknesses add 0.004 in. to all required blank sizes and to the diameters of holes to determine the die size and punch diameters.

Thin hard rubber and all dielectric sheets 0.010 in. thick or less can be pierced and blanked, without heating, in compound dies having spring pad shedders (Fig. 323). This can be done at ordinary shop temperatures and without shrinkage allowances or fractures.

Sheet Celluloid.—The well-known properties of celluloid make it an invaluable material when transparent or thin pliable parts are required. Thin sheets, up to about 0.020-in. thicknesses, are blanked cold in a punch press or with a hand dinking die. Short radial bends up to 90 deg. can be formed cold, but beyond 90 deg. it is advisable to heat the dies. Too much heat causes the celluloid to gum and warp; therefore a controlled gas flame or electric heating element is used. As a measure of safety, it is advisable to use noninflammable celluloid when working it in heated dies.

Thin sheets of celluloid are useful to protect drawings and prints that are frequently handled. Immerse the drawing in a solution of 5 parts of wood alcohol and 1 part of fusel oil, and place it face downward on a sheet of 0.010-in.-thick celluloid. Quickly and with pressure, press out the excess liquid, and the paper will become firmly united with the celluloid. The ink on the drawing should be alcohol proof. Pure ethyl acetate is also an excellent adhesive for celluloid.

Heavy sheet can be pierced and blanked cold; but if a smooth-cut edge is required, one or more shaving operations are necessary, depending upon the thickness. If celluloid becomes dull or opaque after working, its original luster can be restored by immersing in acetic acid. Its specific gravity is 1.35; and its weight per cubic inch, 0.0487 lb.

Treating Celluloid and Rawhide for Punching.—Clean water is used for celluloid, and wood alcohol for rawhide. Wood alcohol makes rawhide more pliable and easier to cut smoothly; it soon evaporates after punching and does not injure the material.

Soft Rubber.—This material can be blanked better when wet. In thick sheets the press should be slowed down to almost a hand speed. Soft rubber is practically incompressible and must have time to flow. Of course this caution does not apply to large open dies or where there is only a small border of scrap left. Weight per cu. in., 0.0341 lb.

CHAPTER VII

PRESS ACCESSORIES AND ATTACHMENTS

Reels, Straighteners, Oilers, Knockouts, and Cushions

Introduction.—Economical press-shop operation depends largely on the materials-handling methods in use. Where quantities are produced in automatic setups, it is imperative to have the right kind of devices for holding coils of strip stock while it is fed to the dies. And it is frequently necessary to add straightening devices to remove the curvature found in tightly wound, springy materials or to remove kinks and waves. For these reasons a variety of coil reels, coil cradles, and strip straighteners are available.

Plain Stock Reels.—Plain ball-bearing stock reels are built in several sizes and types. There are both single and double reels designed for holding one or two coils vertically at one time. A popular type of single reel is illustrated in Fig. 13. Such reels are designed for taking coiled strip from the narrow widths up to 10 in. wide. For wide strips and heavy thicknesses, a "coil cradle" is used.

These reels are adjustable to suit various coil core diameters and are equipped with brakes to prevent "whipping" and "overthrow." They are suitable for flat or round stock. Such reels are arranged for
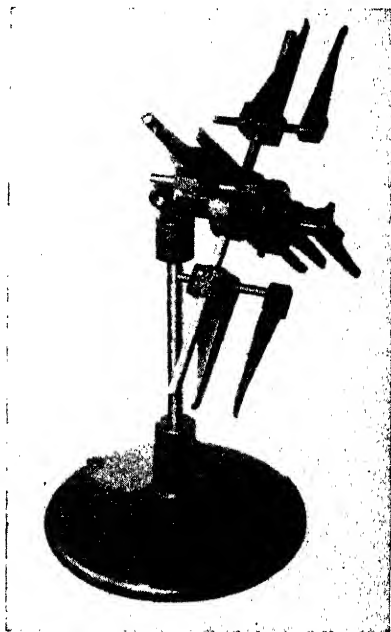

Fig. 13.—Good stock reels should have an adjustable diameter for the coil core, and the reel arms should also be adjustable to suit various widths of strip.

vertical or horizontal operation, or at any intermediate angle. They are also adjustable in height.

Reels are usually placed with their bases on the floor and at the side of the press from which the strip is fed. Some manufacturers find it

advantageous to place the reel base overhead and thus use the reel in reversed position. This allows extra space around the press, and floor space is at a premium in the average pressroom.
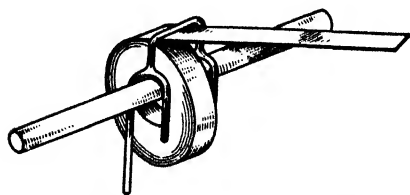

Fig. 14.—In this simple stock reel for small shops, double hairpin forks guide the strip while the coil unwinds on a pipe.

A "Homemade" Reel.—Figure 14 shows a "homemade" reel for light coiled strips. This idea has been successfully applied by small manufacturers. The coil is supported on a pipe resting on two wooden horses. Double "hairpin" forks are placed over the coil to prevent the strip from running wild when unwinding.

Stopping the Press Automatically.—When light or medium-heavy strip is run from a stock reel to the dies, a limit switch can be secured on a bracket attached to the side of the press. The strip is arranged to loop over, or under, a roller on the switch arm. The weight of the strip, or the pull of the feed, holds down the electrical contact that controls the motor while the press is running. When the end of the coiled strip leaves the reel, the switch arm is released, and the press stops automatically. When one operator tends several presses, this arrangement is of considerable advantage. It prevents the strip end from entering the dies unnoticed, which may cause half cuts and sheared, or nicked, cutting edges.

Automatic Reels.—Motor-driven reels are made in several sizes and types. Some of them will handle stock up to 12 in. wide. They are built for vertical coils, as shown in Fig. 15, or are adjustable for tilted positions of the coil and for horizontal coils. Automatic reels are designed to maintain a loop of the strip between the reel and the next unit to which the strip is delivered.

These reels are motor-driven through suitable speed-reducing gears. The motor is controlled by the position of the loop. The strip passes under a roller on a tilting mercury switch, which maintains a loop of the proper size. The switch operates the motor and reel intermittently and only when more strip is required for the dies. Accurate feeding is assured by this arrangement, because whatever type of feeding is employed, the feeding mechanism is never required to pull the strip or operate the reel. Strain on the strip is also entirely eliminated. The mercury switch with its attached arm and roller, under which the strip passes, is seen in the foreground just above the base.

Coil Cradles.—There are two types of coil cradles. In one, the rollers are motor-driven; the other is equipped with a single-roll power

feed which actually pulls the strip. In either case, the coil cradles are adjustable in width, and the coil is motor-driven intermittently by the use of a mercury switch in connection with looping the strip under a roller on the switch arm, as described previously.

The first type of coil cradle, shown in Fig. 16, is used for relatively wide stock and for heavy thicknesses. It readily handles coils up to 72 in. wide, weighing 6 tons. The two driving rollers shown under the coil are connected with a chain drive across the back of the machine.
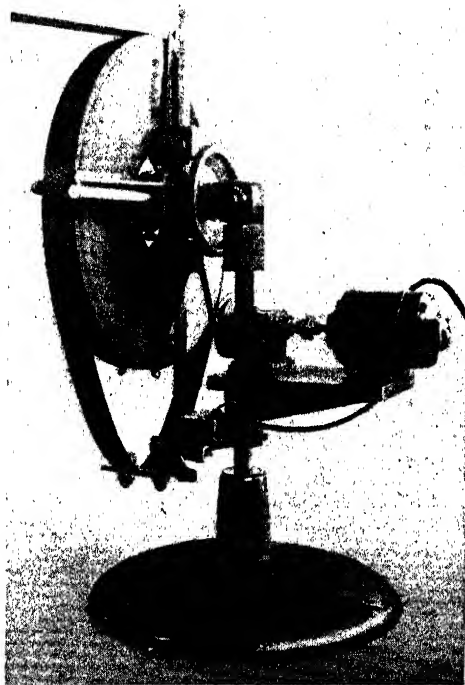

Fig. 15.—This motor-driven automatic stock reel provides economical feeding, particularly where heavily loaded reels are operated through long periods at high speed.

Figure 17 is a view of the other type of cradle set up in connection with a power-driven straightener. The strip shown is steel, 12 in. wide by $\frac{1}{4}$ in. thick. In this case, a single pair of rolls, at the far end of the machine, pulls the strip and causes the coil to revolve on its supporting rollers while unwinding.

Both the coil cradle and the straightener are power-driven and equipped with the usual mercury-switch control. In operation, the cradle maintains a loop of stock for the straightener at all times. This

is done by means of a mercury-switch control which starts the motor and revolves the coil when the loop decreases.   A similar control is attached to the straightener which maintains a loop in the straightened stock between the press and straightener.   A roll feed mounted on the press, not shown, takes the stock from the loop presented by the straightener.   When this loop diminishes, the straightener control

Fig. 16.—Extra sizes of heavy coils, as used in a large number of metal-fabricating plants, are best handled by the coil-cradle principle.   The coil is loaded by a hoist, or by rolling it up an incline.   (*Courtesy U. S. Tool Company.*)

starts the motor and thus provides a new loop.   This equipment is in use by a large automobile manufacturer.

Vacuum-cup Lifters.—A comparatively recent development for lifting large stampings above the strip to prevent interference when the coil cradle feeds the sheet operates as follows.   Soft-rubber vacuum tips are attached on studs from the press ram and on the down stroke engage the blank by suction.   Each of the tips has a hose connection leading to a vacuum pump atop the press.   When the ram ascends, the tips lift the work, leaving the die open for feeding.   At the top of the stroke the vacuum is automatically released, and the stamping
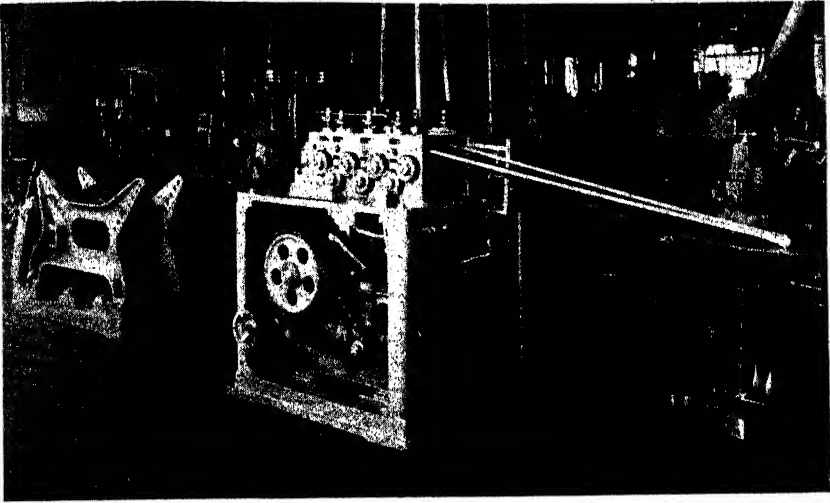
Fig. 17.—Wide- and heavy-gage strip is unwound by a pair of power-driven rolls controlled in a coil cradle, and is then delivered through a power-driven straightener. (*Courtesy U. S. Tool Company.*)
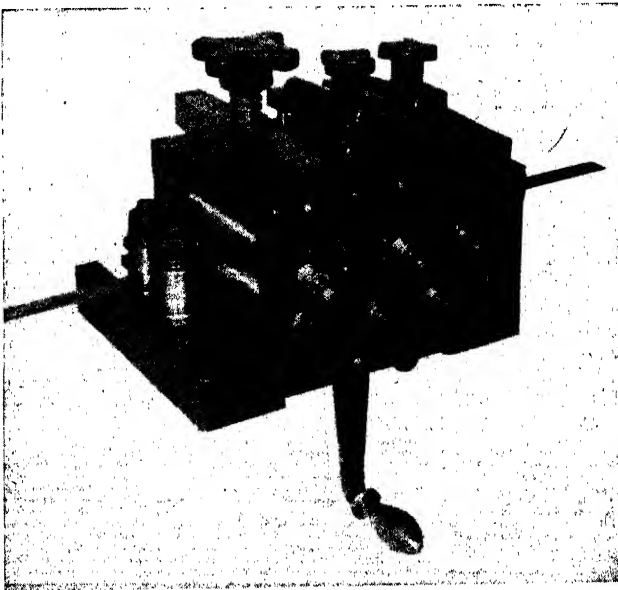

Fig. 18.—A plain stock straightener is used when the feeding rolls on the press have sufficient power and traction to pull the strip through the straightening rolls.

drops down for hand removal. This installation is used in blanking front fenders for automobiles and for other large work.

Plain Straighteners.—The simplest stock straightener for coiled strips is shown in Fig. 18. The strip passes through the straightener, which is placed between the stock reel and feeding rolls on its way into the press and dies. A good straightener insures perfectly flat strips for the die operations. This particular straightener is not power-driven; the strip is pulled through it by the press feed. It is made in seven sizes having five to nine rollers, and for strips up to 8 in. wide.
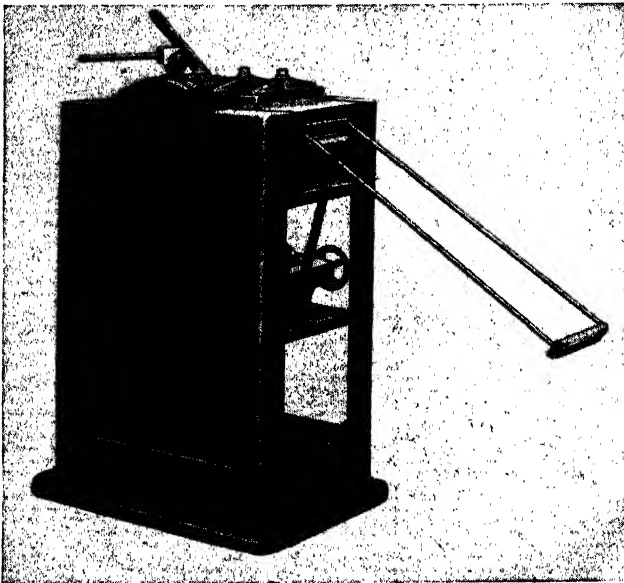

FIG. 19.—This power-driven straightener provides a loop of strip in front of the press-feeding rolls; the loop is constantly maintained by the automatic action of a mercury switch that controls the driving motor. (*Courtesy U. S. Tool Company.*)

The upper rollers can be individually adjusted and are designed to equalize across the strip.

Power Straighteners.—Operation of the rollers in power straighteners (Fig. 19) is similar to those in plain stock straighteners. These straighteners are intermittently power-driven through a loop in the strip that passes under a roller attached on the arm of a mercury switch. All the lower rolls are power-driven. The top rollers are individually adjustable, and provision is made for starting a new strip without disturbing the adjustments. The upper rolls are designed to equalize across the strip. A variable-speed control regulates the advance of the

strip. These straighteners are built in several sizes and will take coils up to 12 in. wide and weighing 6 tons.
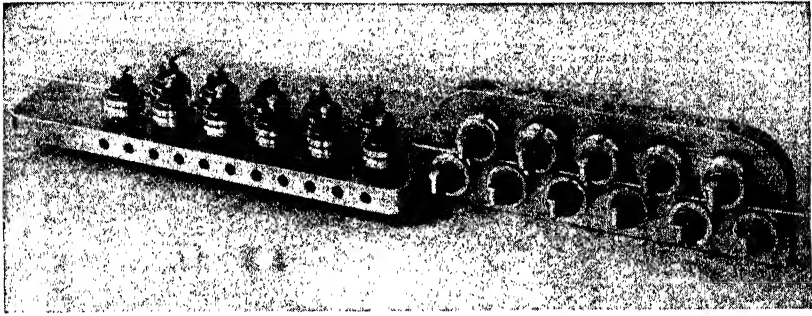

Fig. 20.—Two-way straighteners are used for straightening flat wire or various tubular and rod sections. The side faces of the rolls are grooved to conform with the cross section of the stock.

Two-way Straighteners.—A double straightener, shown in Fig. 20, is adapted for straightening round, square, or flat wire and strips or the equivalent. It consists of two sets of straightening rollers, one set being vertical and the other horizontal. All rollers are equipped with oil cups and individual adjustments. For straightening strips, only one set of the rolls are used.

Stock Oilers.—The stock oiler, shown in Fig. 21, handles stock up to 8 in. wide. Strip passes between two felt pads saturated with oil furnished from a top trough and supplied by the tank. The strip edges are guided between two adjustable rollers shown at the front. The height of the device can be adjusted.

Adjustable Knockout in the Ram.—This device is used with inverted dies where the die block is attached to the punch holder. Its outstanding feature is the large range of adjustment. It can be set to operate at any height of the press ram, even leaving the work partly
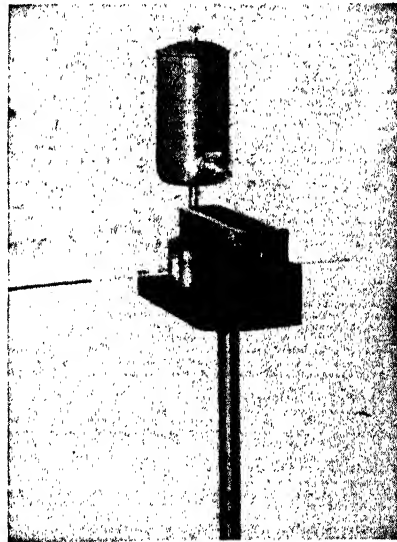

Fig. 21.—Both sides of the stock are lubricated by passing the strip through this device before the strip reaches the press and tools; this prevents bare-metal contact between the cutting members.

in the die, if desired. This is a great improvement over the ordinary ram knockout, which functions only near the top of the press stroke. It can be readily attached in any press as illustrated in Fig. 22.

In the illustration, it should be understood that the ejector is composed of two separate parts. One part is the slotted bracket on which is mounted an adjustable roller "trip" and is positively secured at
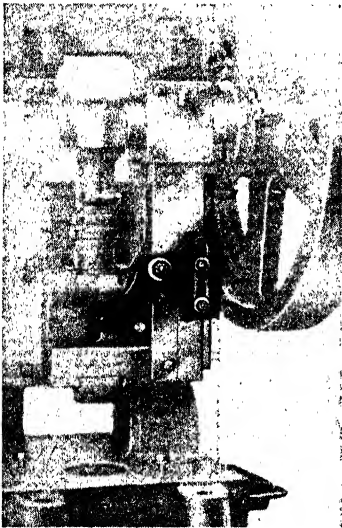

FIG. 22.—This knockout has a "trip" attached on the ram gib. The knockout itself operates through a slot in the ram. It can be adjusted for ejecting work from dies at any point in the ram ascent. (*Courtesy Waterbury-Farrel Foundry and Machine Company.*)
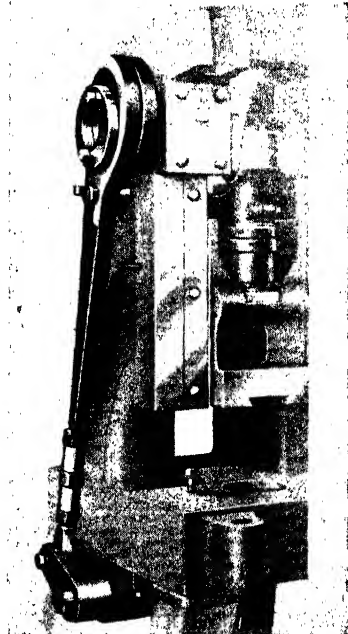
FIG. 23.—A die knockout pin is elevated through the press bed by a cam underneath the pin. The cam is actuated by an attached linkage shown in connection with the crankshaft.

the right side of the press slide. The other part is the moving member and is attached on the front of the ram by a fulcrum pin; as shown, it contacts the positive roller when the ram ascends.

Vertical Knockout Pin under the Die.—With this attachment, a vertical knockout pin is operated by a cam located under the press bed. The cam is "keyed" on a horizontal rocker shaft, which is extended for the attachment of a link and side arm connected with an operating

eccentric on the crankshaft (Fig. 23). Height of the knockout is adjusted by using a turnbuckle placed in the arm. The pin rides on the cam and can be made a part of the tool or left in the press.

Spring Knockout.—This device is designed for the same purpose as the cam knockout but is cheaper to install. A pipe is vertically attached under the center of the bolster and is used to encase a long compression spring. The knockout pin is operated by a long threaded rod passing vertically through the casing; an enlargement on the rod rides on top of the spring. Force of the knockout is controlled by the action of the compression spring, and the power of compression is adjusted by nuts beneath a pressure pad at the lower end of the casing.

Cushioned Pads.—Four principles are employed in operating cushioned pads attached under a bolster plate. The four types are spring cushions, rubber cushions, air cushions, and hydraulic cushions. Each type is made commercially. The pad faces are usually round and are flush with the face of the bolster or a suitable distance below. Pads are usually 4 to 8 in. in diameter or larger if necessary.

In the smaller sizes, one long compression spring is used around a vertical stud tapped into the pad center. The lower end of the stud passes through a U-bracket attached under the bolster. Adjustable locknuts on the stud, under the bracket, control the compression spring pressure. Other types have a barrel-spring chamber cast in a single unit, with flanges on the body for attaching under the bolster. These types contain one or several compression springs and exert great power (Fig. 24).
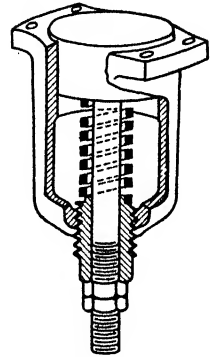

FIG. 24.—Spring cushion pads, attached under the bolster plate, are adjustable as to spring pressure, and may contain one or several springs.

In the rubber cushions, semisoft rubber is substituted in place of the springs for the cushion element. The rubber bumper is clamped under the pad by lock nuts underneath the unit. Many grades and diameters of rubber bumpers and various lengths, with suitable holes through them, are available.

A recent hydraulic blank-holding cushion exerts 100 tons compression. In use, the press-tool die holder is clamped on the bolster plate over the pad cushion. Vertical pins, under the shedder or the blank holder in the die, project through the die holder with the ends resting on the pad. In operation, the pad cushion action is a stiff resistance when the ram descends with the punches against the work and with the

shedder or blank holder underneath. The resistance is adjustable to suit the conditions. The pad cushion and shedder follow up the punch in ascent and deliver the work free of the dies.

Pneumatic Die Cushions.—Spring- or rubber-actuated die cushions are not satisfactory for deep-drawing operations because of the difficulties in controlling the resistance pressure of springs and rubber, which increases with the depth of the draw. This difficulty is eliminated by employing pneumatic die cushions. This type of cushion provides unvariable blank-holding pressures throughout the operation.

The pneumatic die cushion is a portable unit which can be applied under dies already in use. The entire area of the piston head is available for knockouts, ejectors, and other die-pressure actions. As in the case of hydraulic cushions, the pneumatic cushions are adaptable for blank holding and drawing, compound blanking, and forming operations. Underneath the unit is a handwheel adjustment which compensates for the variation in bolster-plate thickness.

The usual type is an externally corrugated air cylinder built in two designs; one of them is a cylinder with a single piston, the other has a double piston, as illustrated in Figs. 25 and 26. Several other types are made to suit various conditions and purposes. The cylinders can be superimposed for use in large presses for heavy operations. All of them operate on air pressures up to 100 lb. per square inch.

The cylinder is attached either under the press bed or through the bed and under the bolster plate. Pressure pins from under the blank holder in the die extend down through guiding holes and rest on a pin plate atop the cylinder head. It is to be observed that the piston remains stationary while the cylinder moves. In other types these conditions are reversed. Air is introduced above the piston heads by a pipe connection, or by a flexible hose if necessary to remove the cylinder frequently. These units are easily installed without altering previously used dies.

These cushions are sometimes used in groups under the pressure pads in double-crank presses. They are then evenly distributed in multiples of two or more cylinders, depending on the size of the press and the nature of the work.

For changing a single-action press to operate in double action, these cushions are fitted above the slide with the pistons projecting through and used to accomplish the double-action feature. For large, wide presses, as many as 10 or 12 double cushions have been successfully used in this manner. Another set of cushions underneath the bolster plate, operating in the usual manner, makes a triple-action press of a single-action machine. Operated by 100-lb. air pressure, a 12-in. single
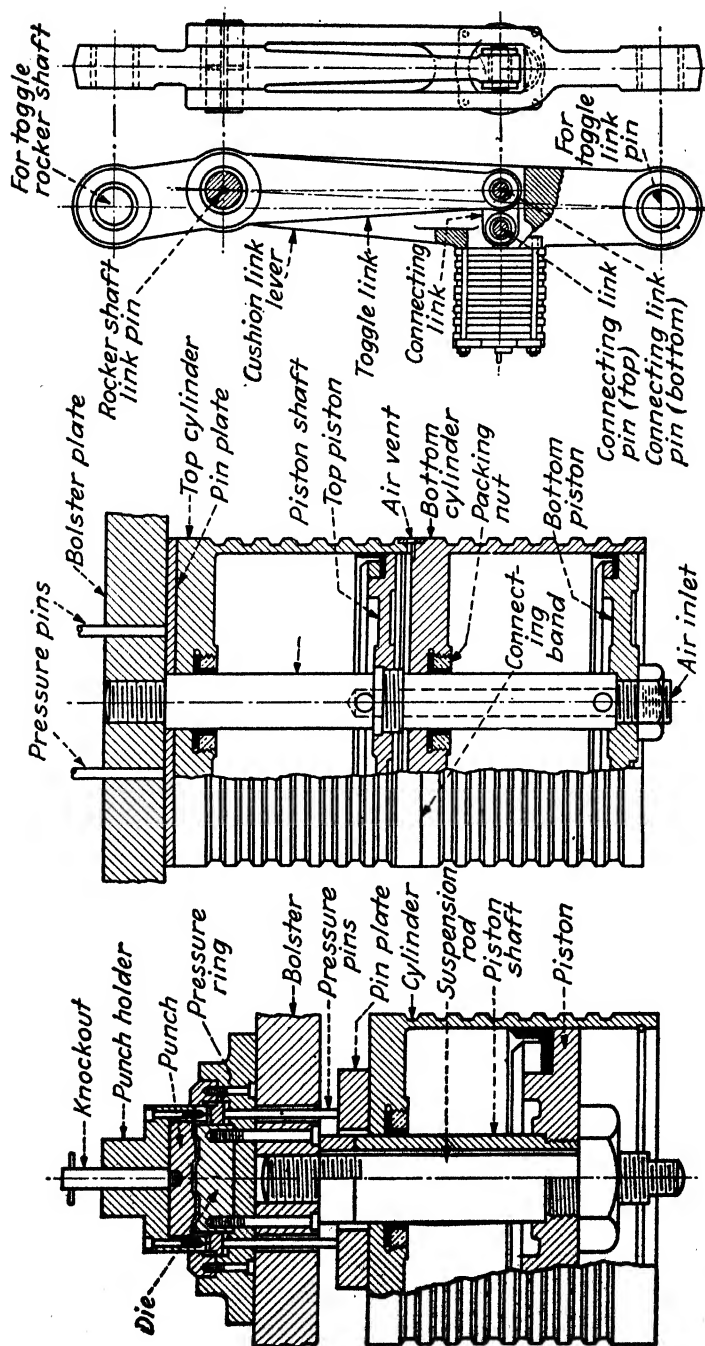
FIGS. 25 AND 26.—Single- or double-piston pneumatic die cushions provide unvarying pressure throughout the depth of the operation, and they can be installed without altering previously used dies. FIG. 27.—Pneumatic toggle links are used to replace the original positive links in a press, and have the advantage of compensating for variations in the thickness of the work. (*Courtesy Marquette Tool & Mfg. Company.*)

piston cylinder with a 6-in. stroke exerts approximately 5.6 tons, and double-piston cylinders 11.2 tons.

A triple-piston cylinder is also built with three superimposed compartments. These run up to 40 in. in diameter and have 186 tons capacity. Stroke of the cushions can be anything from 1 in. up, depending on the diameter. They are provided with hand-control valves. It is not unusual to draw shells with the depth of draw exceeding the diameter when the presses are fitted with these die cushions, because of the constant uniform pressure that is supplied to the draw ring.

Pneumatic Toggle Links.—A cross-section view through a pneumatic toggle link is shown in Fig. 27. Air-operated toggle links are made to fit all sizes and types of toggle drawing presses, both single and double crank. This equipment can be made to replace the links originally furnished. Their use is to compensate automatically for variations in thickness of material from sheet to sheet or in different parts of the same sheet. The result is a corresponding reduction in "wasters" and protection against overstressing the capacity of the press. The change in the thickness of the sheets during drawing operations is also compensated for when using these flexible links. This is accomplished by slight changes, during operation, in the lengths of the links, under the control of the closely regulated pressure in the air cylinders, which are a part of the links.
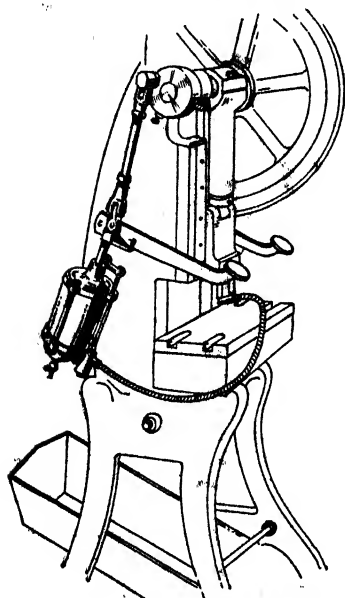

Fig. 28.—This air-compressing cylinder is operated by the crankshaft. A flexible tube leading from a valve delivers a blast of air which is controlled by the descent of an attached finger on the piston. The nozzle of the tube directs the air for ejecting finished work from the tools; it also removes loose pieces of scrap and keeps the dies clean.

The use of these links permits many advantages, such as cheaper and less uniform sheets, by automatically adjusting the blank holder in drawing dies to suit variations in the thickness of the sheets. They prevent press breakages caused by inaccurate adjustments of the blank holder or by the frequent mistake of feeding more than one blank in one operation. In hot forging, if a piece is too cold, the linkage movement compensates for the different temperature and saves fracturing the ress. These links are usually furnished in sets of four.

Other Applications of Pressure Cylinders.—Pneumatic and hydrau·lic cylinders are applied in die operations for several other purposes. In locating and clamping large pieces for folding, riveting, and assembling dies, the clamps can be air operated.

In another case an air-pumping cylinder is attached on the left side of a press frame, under the crankshaft. Its piston is connected with a driving arm to a crankpin screwed in a disk on the end of the shaft. A pipe from the cylinder leads down to the press tool. The air pressure generated by the revolutions of the crank is used for ejecting and blowing finished pieces from the dies, as shown in Fig. 28.

A more elaborate installation comprises an air pump continuously operated by the flywheel. In this case, the air is usually pumped into
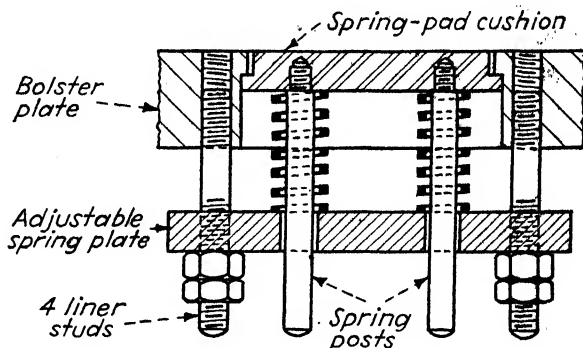

Fig. 29.—A hardened cushion plate is attached flush within the press bolster and is provided with adjustable spring pressure; this makes it unnecessary to attach spring pressure units under the shoe of each individual press tool that needs them.

a small reservoir and piped to the dies. An air-control valve near the dies is operated by a lug on the ram or by an arm on the end of the crankshaft. It is timed for tripping a jet of air at the critical moment, for clearing the work from the tool. This equipment has been commercially developed and is an economical substitute for a shop air line. Air is often introduced into dies by means of a horizontal hole drilled in the die holder. From this hole, lateral holes lead the air to the most advantageous points for removing the work.

A Bolster-plate Cushion for Universal Use.—Figure 29 shows the design for a very simple and effective spring-pad cushion which is usually made by the manufacturer using it. The cushion plate is of tool steel, hardened and ground. The spring thrust is taken by the spring plate; this plate is positioned by four liner studs attached in the bolster, on which adjusting lock nuts are mounted, as shown. The number of spring posts are from 2 to 12, according to the press size and

tool needs. Vertical pins, arranged under the die members to be depressed, are made to slide through the die shoe with their lower ends resting on the surface of the hardened cushion. The cushion may be round, square, or rectangular, as required, and its surface is flush with the face of the bolster.

There are a large number of bending, forming, compound, and combination dies, in which shedders or other die members must be depressed against springs during the downstroke of the punches. To avoid the necessity of attaching a spring-plate unit under the die shoe of each tool, it is better practice to provide this universal spring pad within the press bolster plate. The area of the pad should be of a size sufficient to suit the largest number of such dies that require it.

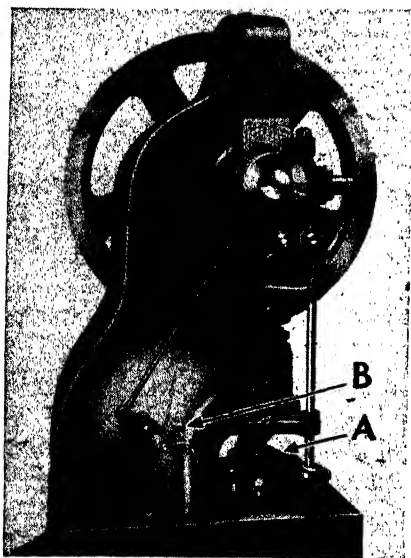**Flip-off Fingers.**—Figure 30 shows the "flip-off" principle. It is used on drawing and forming dies for clearing the finished pieces from the tool when the punches ascend with the ram. It consists of a long horizontal finger A, attached on the lower end of a vertical rocker shaft; and in operation it sweeps across the face of the die and removes the work.

FIG. 30.—The long horizontal "flip-off" finger A is designed to sweep across the press tool and remove finished pieces from the dies when the punches ascend. (*Courtesy Waterbury Farrel Foundry & Machine Company.*)

The forward movement of the finger is operated by a tension spring, and the backward movement by a suitable cam on the crankshaft. Revolution of the cam causes the roller arm to descend and oscillate the rocking lever and to force the finger back until the roller arm drops over the toe of the cam. The finger is then instantly pulled forward by the tension spring. A finger-motion automatic stop is also shown at B, in this illustration, and its action is described under Fig. 63.

Scrap Cutter.—A ram-operated scrap cutter is shown in Fig. 31, as applied at the rear of a straight-side press. The press is equipped with a roll feed at its front. The upper cutting blade is attached to the ram by a turnbuckle connection and operates to cut off the end of the scrap strip with each stroke of the press. Difficult removal of large

unwieldy piles of scrap strips from the pressroom floor is thus avoided.

A similar device for cutting scrap strips at the left end of gap-type presses is also available. In this case, the cutter is operated by a crank arm connection from the end of the crankshaft. This is a dangerous attachment for the safety of the operator's fingers unless it is fully protected by safety guards.
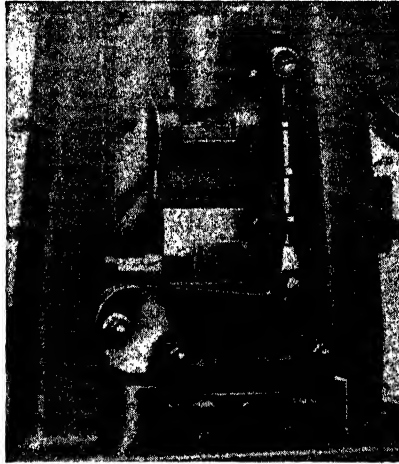

FIG. 31.—Scrap-cutting blades, operated by the ram, are applied at the rear of a straight-side press and chop the scrap frame into blanking-center lengths. The scrap-handling problem is thus easily solved.

Another serious fault with this device is that it prevents the operator from pulling through the last end of the strip with his left hand. However, by using a roll feed, equipped with a scrap cutter, as illustrated in Fig. 46, this trouble is entirely avoided.

It is also common practice to build the scrap cutter in the die itself. The scrap is severed by a punch cutter which shears against the left edge of the die block. Scrap cutters operate with each cycle of the press and sever the scrap into blanking-center lengths. A steel barrel is placed to catch the pieces.

CHUTES, MAGAZINES, HOPPERS, ROLL FEEDS, AND DIALS

Blanks and Shells Are Transferred to the Dies by Either Manual or Automatic Devices and Provide Safer and Faster Operation than by Hand Feeding

Roll, Slide, and Hitch Feeds for Strip and Coil Stock, in High-speed Presswork, Permit Maximum Output with Safety

Introduction.—The pressroom that is not equipped with modern feeding chutes and slides can use simple manual feeds just as satisfactorily in many cases. With an automatic stop and hand feed, short strips can often be advanced as fast as with a roll feed. The advantages in using a roll feed are obtained when long strips and coiled stock are employed, enabling one operator to tend several machines. For redrawing shells and forming work the operator shown in Fig. 32 can feed shells through the attached chute to the die as rapidly as though a mechanical feed were employed.

Spring-pad Feeding Chute.—Figure 33 shows two views of a first-operation circularly drawn shell with a large flange. An elliptical flange is to be trimmed to the outline indicated by the dotted line. The trimming die is sketched in Fig. 34 and is shown inclined as used in the press. The spring-pad chute is a plate with a central channel cut parallel with its length. Width of the channel is such as to provide clearance for length A of the work. And the chute is sufficiently long to take one more shell than the one being trimmed. This is an inverted die, with the die attached to the punch holder and with the punch below it on the die shoe.

After placing a shell in the chute, the shell slides by gravity over the trimming punch and stops against the lugs shown in the end view of the

FIG. 32.—In redrawing small shells an operator can keep up with the press strokes by pushing the pieces through this simple channel chute.

chute. A rectangular opening is cut through the chute which clears the width and length of the flange around the shell. This opening is located symmetrically over the trimming punch.
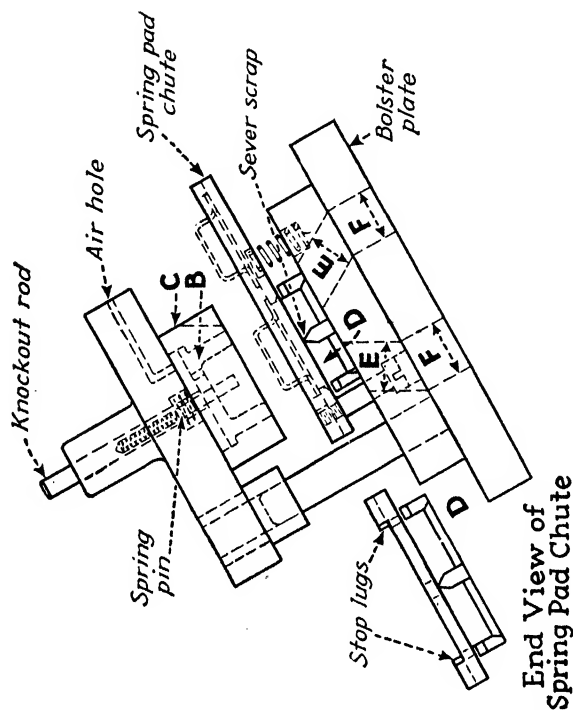
Spring pad chute

Air hole

Knockout rod

Sever scrap

Bolster plate

Spring pin

Stop lugs

C B

E

D

E

F

F

D

Fig. 34.

End View of Spring Pad Chute
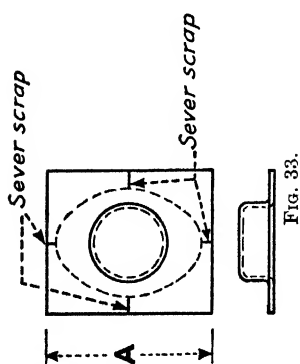
Sever scrap
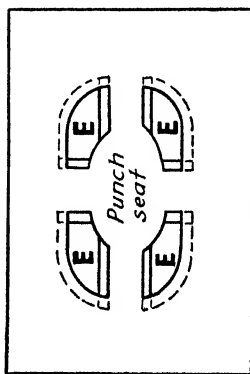
Sever scrap

Fig. 33.

Punch seat

E E

E E

A

Fig. 35.

Figs. 33, 34, and 35.—The large flange on the circular shell, Fig. 33, is trimmed to an elliptical shape while held against stops in the spring-pad chute on the inclined die, Fig. 34. The chute holds two shells, one in position for trimming, and the second ready to slide in place through gravity after the first shell has been trimmed and ejected.

When the ram descends, an opening in shedder *B* fits around the outside diameter of the circular shell body and thus positions the work accurately before die *C* descends, depresses the chute, and trims the

flange over punch *D*.   When the ram ascends, the work, having been cut into the die, is carried up with it and is ejected by the action of the combination knockout rod and the spring ejector pin, seen in the tool sketch.   The finished work slides out behind the press.

The trimmed scrap frames are severed by the ram descent into four equal pieces.   This is done by the upper die after trimming.   The die crowds the scrap frames into contact with four cutting chisels attached on opposite sides of the punch, the punch being flared around its base, as shown.   When several frames have been cut, and more of them follow, the chisel angles force the pieces of scrap away from the punch and in contact with the flare.   As more scrap is cut, the pieces below are forced out into four angular clearance holes *E*, through the die holder, and finally out through clearance holes *F* in the bolster plate. The plan for the angular holes through the die holder, showing the seat for the trimming punch and chisels, is shown in Fig. 35.   Holes *E* discharge the scrap through holes *F* in the bolster.

If holes are to be pierced in the flange, piercing punches are attached in a punch plate just above the shedder.   They pass down through the shedder with their faces flush with the die.   Die holes are provided in the face of the trimming punch.   Unless the output is sufficient to justify the expense of using this method of scrap disposal, holes *E* and *F* are omitted, and the scrap is occasionally removed with a hand hook.

Automatic Magazine Chute.—In Fig. 36 a cast-iron chute, attached to the front of a press bolster plate, is provided within by a double-action pawl escapement, or work release, operated by linkage connected with an eccentric on the crankshaft.   The blanks are stacked in the chute behind the pawl hooks.   At each crank revolution, one piece is released by a rocker movement of the hooks and slides into the die against suitable stops, where the punch descent locates the work before piercing, forming, trimming, or other operations.

When the pawl hooks nearest the die are raised to release a blank, the rear hooks are simultaneously lowered, which checks the rear column of blanks and prevents releasing more than one piece in each press cycle.   The lateral distance between the pawl points is *less* than the width of the blanks.   This provision allows a space for the rear hooks to enter while withholding the column.   This device not only increases production but removes the operator's fear of injury.

A Vertical Magazine Chute.—An automatic magazine chute attached to the bed of a "rear-wheel gap press" is shown in Fig. 37. The motion of the pitman rod and crank connection feeds one piece at each press revolution from the bottom of a stack of blanks.   The blanks are stacked in the vertical magazine seen in front of the press

ram. The feeding mechanism advances a sliding plate, which contacts one piece and slides it over the die. The piece registers against rear stops, not shown, and in tension contact with a spring ejecting plunger, seen at the left. When the ram descends, the punch forms the piece; and when the punch ascends and frees the piece, the spring ejects the finished work through the horizontal chute shown at the right.
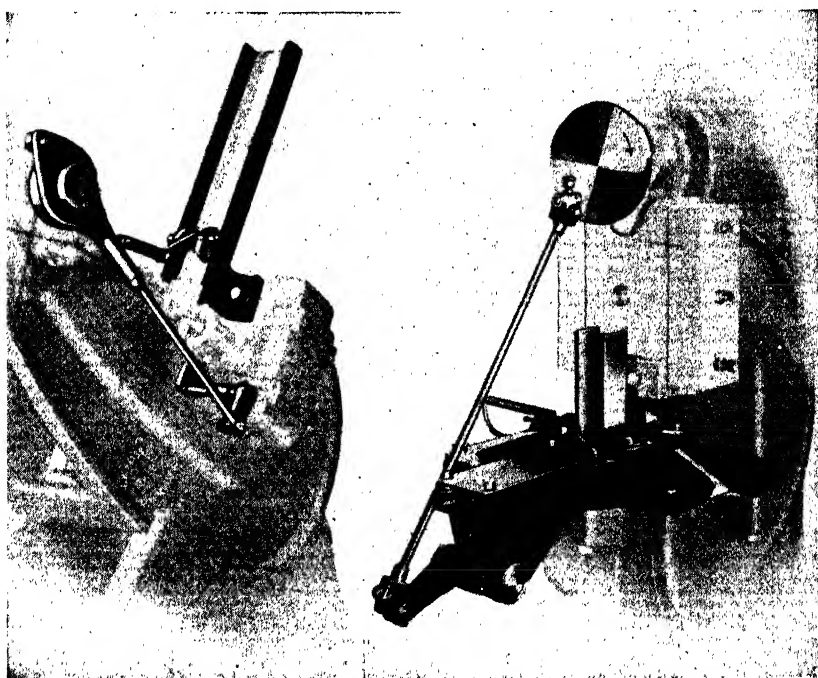

FIG. 36. FIG. 37.

FIGS. 36 and 37.—These automatic magazine chutes are operated by linkage connected to a crank or eccentric on the crankshaft, and feed one blank from the magazine at each press stroke.

Magazine Chute Built into the Die.—In another application of magazines, the feeding device is built into the die itself, the important requirement being that the quantity to be made justifies the expense. The saving of time to be figured, over hand feeding, ranges from 50 to 100 per cent. It is evident that an operator cannot catch every stroke of a press running at 120 to 200 strokes per minute, but the automatic chute and magazine feed, shown in Fig. 38, will not fail to catch them all.

Blanks are stacked in a magazine at the front of the die. The view shown in the illustration is actually the side and rear of the tool. A

sliding plate, with a U-slot through it, is arranged in a guide under the stack. The sliding plate has the same thickness as the blanks. One blank is taken from under the stack by dropping into the U-slot, when the slot is under the stack and the press is open. The angular slot, at the sides of the punch holder, moves the slide and blank forward when the ram descends and places the blank over the die, just before the punch fully descends. A notch is sheared in the blank by the pointed punch shown in the rear. When the ram ascends, this punch carries the blank above the initial stops and strips it off against the bar shown
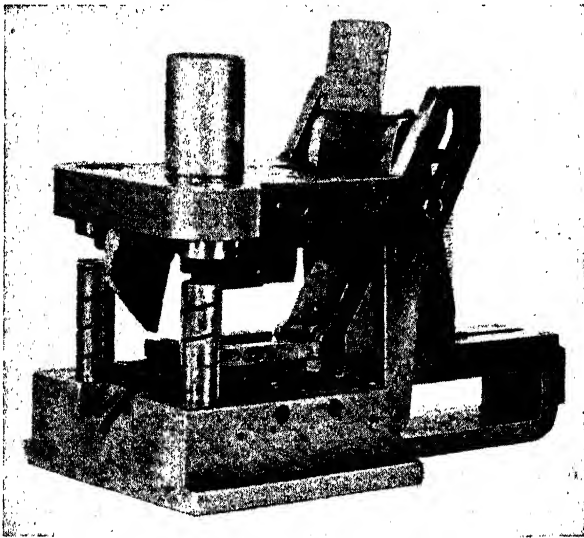

FIG. 38.—Where the quantity of work justifies the expense, a vertical magazine and horizontal chute feed can be built into the dies.

across the dies. The press being inclined, the finished piece falls out in the rear.

Manually Fed Magazine and Chute.—If one can design a tool that makes the operator feel safe in using it, he will work more quickly and easily. A device that meets this requirement is shown in Fig. 39. It operates on the same principle as the automatic feed, shown in Fig. 38, except that it is manually fed and is cheaper to build. The slide works between two positive stops, each of which must be fully contacted to feed the blanks correctly. The difficulty in using this chute is that the press may be tripped before the blank has been fully placed. This can be controlled by a clutch-releasing device, or limit switch, connected to the clutch. In the second case, the switch must be contacted by the

advanced slide when the blank is correctly placed over the die, before the clutch can be tripped.

The labor required to operate the slide in and out is so slight that the operator can use his other hand to gather and place blanks in the magazine. Eighty blanks per minute is about the safe limit for light blanks manually fed to a die. A good operator can attain this rate without fatigue.
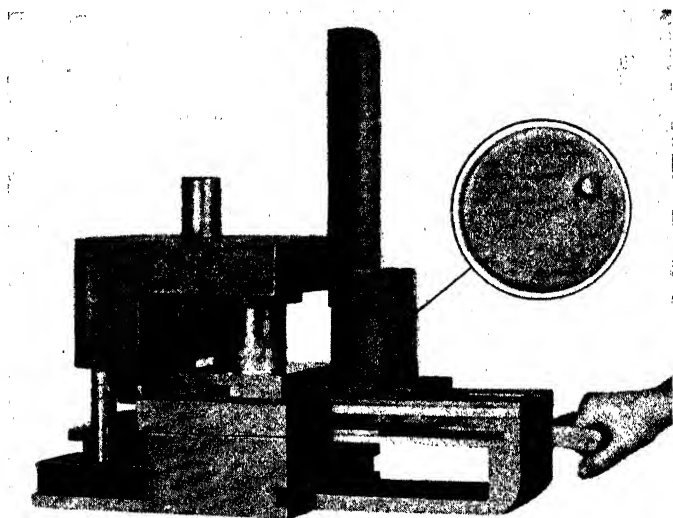

FIG. 39.—This magazine feed is manually operated, is cheaper than the automatic types, and affords safety in operation.

Blanks Fed from a Magazine by Air.—In a pneumatic feed built into the die, a cylinder is connected with the compressed-air line through a trip valve. The piston controls the movement of a slide plate under a magazine of blanks. The slide maintains a line of blanks in the chute and feeds one piece forward into the dies, at each press cycle. Figure 40 shows the general design. The advantage in using an air feed is its easy control. The feeding throw can be readily altered to suit blanks of different widths, and feeding can easily be timed.

Stacking Chutes.—Blanks can easily be "stacked together" in chutes after pushing them through the dies. Such blanks as addressing machine plates, rotor and stator laminations, and similar parts which are subsequently "magazined" in assembling fixtures must be stacked together for this purpose. When stacked in chutes, or strung on rods as is sometimes done, the blanks can be removed in bunches, and this avoids rehandling them at the assembling dies or machines.

The head of the chute, for stacking blanks, passes through a clearance hole cut in the bolster plate.   The head is attached to the bottom of the die shoe and directly under the blanking-die opening.   The chute is of angular welded frame construction; its interior cross section is simply a continuation of the blank clearance hole through the die shoe.   The frame of the chute sweeps down from the die and leads out
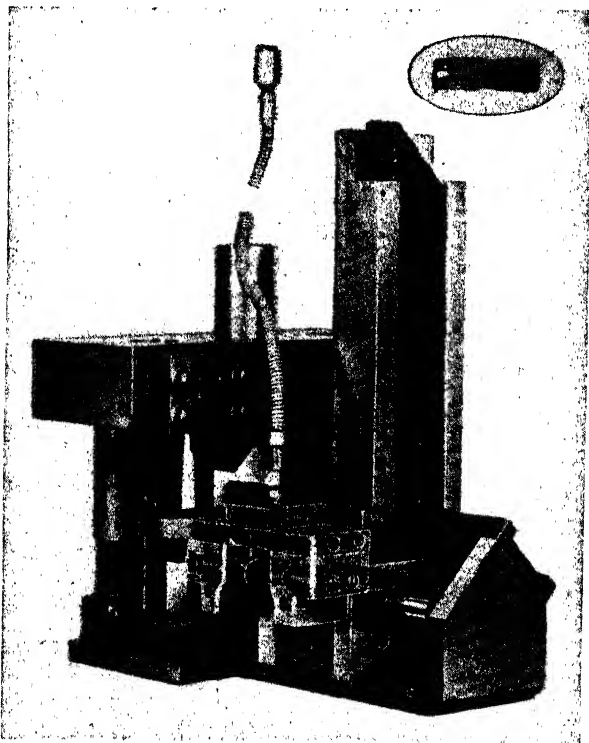

Fig. 40.—In this pneumatic-feed magazine, different widths of blanks can be fed into the die.   The piston stroke can be adjusted to suit different blank widths.

at the rear of the press.   Some prefer using the "S-type chute" in which the unloading end leads out on a table of convenient height for removing the blanks at the rear of the press.

FEEDING WORK FROM HOPPERS

Oscillating-arm Hoppers.—This principle is one in which the hopper is divided in two equal parts by a blade that swings on a radial arm.   The blade is provided with a longitudinal channel along its upper edge.   The "sweep" of the arm is determined by a center pin attached to the chute that leads from the hopper, and to this pin the

arm is attached. This type of hopper is useful in feeding headed articles like bolts, rivets, and screws. The idea is to deliver the pieces "heads up" into the chute outside the hopper.

The hopper sides are inclined toward the blade and make the usual slanting floors that tend to centralize the pieces over the blade channel. Slanting floors are a common factor in practically all hoppers. The arm and blade, in swinging up from the hopper floors, carries the pieces that have fallen, heads up, into the blade channel. At the top of the stroke, the blade channel coincides in line with the slanting chute outside the hopper, and the pieces slide into it by gravity. The oscillating arm and blade are activated by contact with a revolving cam or by an attached pitman arm.

Hopper for Feeding Cylindrical Work.—This type is simply a vertical disk wheel which revolves through the center of a hopper. The edge of the wheel is provided with equally spaced hooks, or prongs, for feeding cylindrical shells into a "slant-away" chute outside the hopper. The spaces between the hooks must be greater than the lengths of shells. When feeding solid cylindrical pieces, the hooks are bent straight to coincide with the wheel radius.

In operation, the shells roll under the wheel from the slanted floor in the hopper and into a V-groove directly under the edge of the wheel. If the closed end of a shell lies against a hook, the wheel carries it up to the chute where it is "tipped" into the mouth of the chute by gravity. On the contrary, an open end of shell will engage itself over the hook and cannot turn into the chute; it is therefore carried over the top of the wheel where it falls back into the hopper by gravity. Thus all the shells are delivered into the chute with closed ends in the same direction.

Agitating Hoppers.—It is sometimes necessary to agitate the hopper itself to compel the work pieces to move forward toward the chute for delivery. In such cases the hopper is provided with an activating device; the hopper is "pivoted" near its throat and is "rocked" either up and down or sidewise, whichever is necessary, by an attached pitman arm connected to a crank.

Hopper and Magazine for Feeding Shells.—There are many designs of pawls, escapements, and wire or hair wheel brushes installed in hoppers for agitating shells, or blanks, causing them to loosen when jammed and to pass along by gravity or other means. A mechanical solution for this problem is usually a difficult one to solve successfully, yet there are a number of commercially developed hoppers on the market for feeding standard shapes of work.

Like the "log jam" in a river, it is always possible to find the "key piece" which, when loosened, will release other pieces and thus restore

a normal flow. However, after the pieces in a hopper have been loosened, two other problems arise. (1) The freed piece must be detained to permit the parts ahead to arrange themselves in proper order. (2) A mechanism is necessary to compel each consecutive piece to align itself with the same end forward.

Figure 41 shows hopper A, into which a quantity of shells are thrown promiscuously. The shells must be delivered through maga-
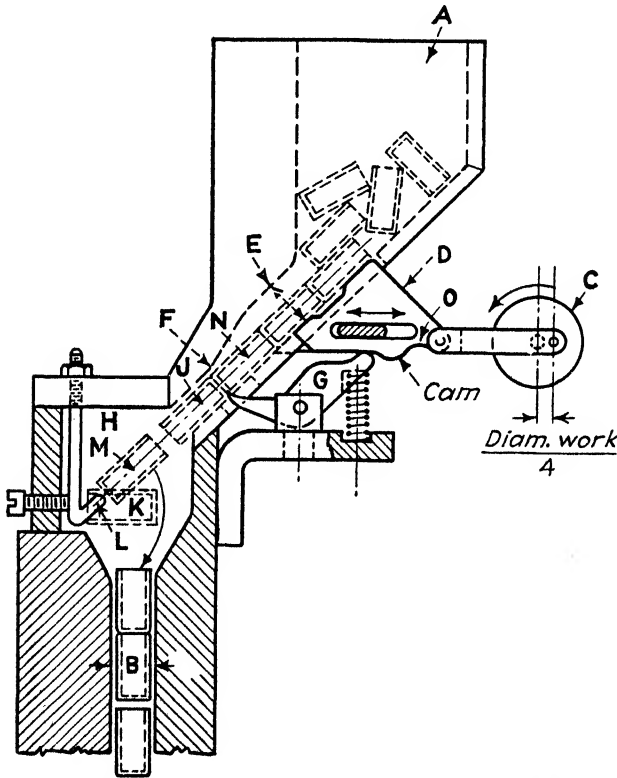

FIG. 41.—Shells thrown promiscuously into hopper A are automatically transferred into magazine B, with their closed ends down.

zine B with closed ends down. Crank disk C, driven by a slow belt, reciprocates the triangular slide or agitator D, which loosens a possible jam of two shells at E, which is the entrance to the magazine. The height of E is approximately $1\frac{1}{2}$ times the shell diameters, and the height and width tapers to a clearance for one shell diameter at point F. Space E is not wide enough to allow crosswise pieces to enter at a greater angle than 45 deg.

If two shells, side by side, jam at *E*, the agitator raises one of them and permits the other shell to gravitate toward *F*. Simultaneously, the point on pawl *G* is elevated by a cam on slide *D* and not only prevents the released shell from entering chamber *H* but also backs up the line of oncoming shells and loosens them. Shell *J*, which has previously passed the pawl, can now enter chamber *H*.

When the *open end* of a shell, such as *K*, enters *H*, its mouth falls over hook *L*; it therefore turns, closed end down, and enters magazine *B*, as shown. If a shell, such as *M*, enters *closed end* first, its head hits a point on the hook; the shell rebounds slightly and then gravitates into *B*, head first. *D* and *G* are thin blades, and the speed of crank *C* must be adjusted to permit the point *G* to release one shell *N*, when indent *O* has been reached at the "instroke." Other shells cannot follow *N* because the agitator holds the following shell near the roof of *E*, until the stop hook is restored, when it approaches the extreme "outstroke." It is observed that a full stroke of crank *C* is equal to half the diameter of the pieces.

Hopper Chutes for Eliminating Misplaced Work.—In Fig. 42 a "T-slot chute" is mounted on base plate *A*, through which a line of blanks are fed, as *B*, *C*, and *D*, from hopper *E*. The chute is positioned horizontally and leads away from the hopper at right angles, as shown. This is an interesting type of the many designs of hoppers and magazines for the purpose of automatically feeding blanks, shells, and similar pieces of work, in a specified direction. The feature is often necessary in feeding work into dies and special machines.

A quantity of blanks are thrown promiscuously into the hopper, and they must be delivered from the chute at *F*, each one with its "hole end first." In the throat of the hopper is a circular bristle brush wheel *G*, which revolves in the direction indicated by the arrow. The brush sweeps the blanks into the chute from the hopper throat. To prevent the blanks from choking the throat, slide *H* is arranged to reciprocate eight or more agitator pins, as shown under and around the brush in the plan view. If the blanks lie crosswise or fail to be swept out, additional agitator pins to loosen them can be added in block *H*.

The eliminating station is at *J*; it automatically removes all the misplaced blanks in the line. This station is simply a clearance hole, section-lined in the figure, which is cut through plate *A*; its under edges are beveled, as shown in the section view at the right. The outline of the hole corresponds to the shape of the blank and is $\frac{1}{32}$ in. oversize, all around. The directional position of the hole is the same as the blank to be eliminated.

A small rubber-tired wheel K is mounted over the hole center.   The wheel has frictional contact with the surface line of blanks.   The brush sweeps the line of blanks ahead of the hopper; but if one passes under
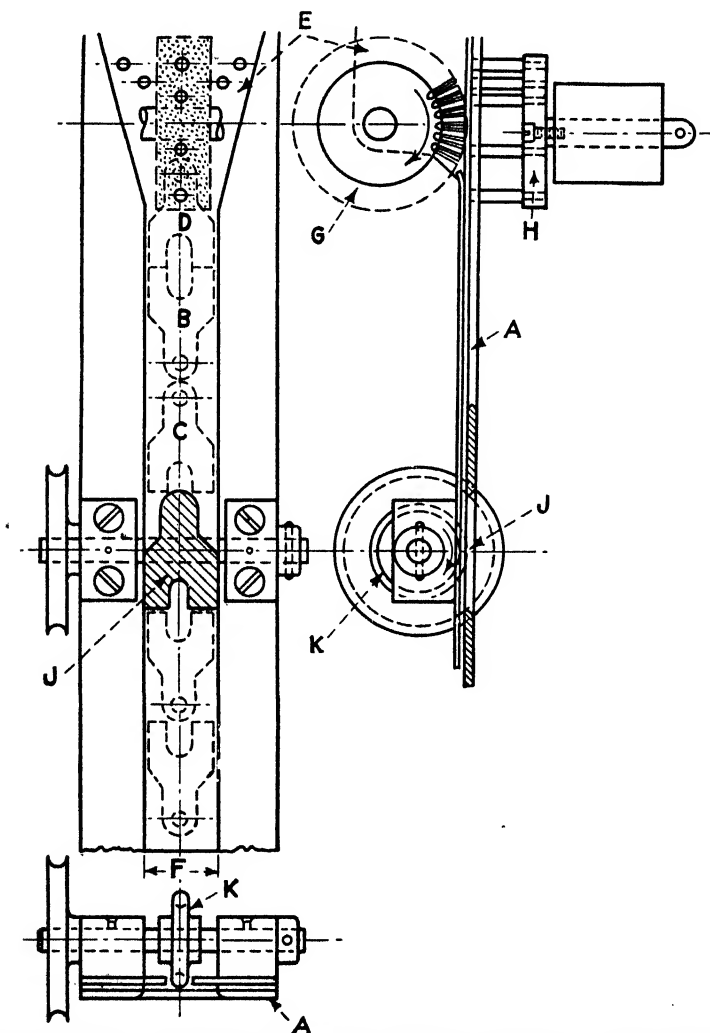

FIG. 42.—Hopper and chute for automatically feeding and removing misplaced blanks.

wheel K in the same directional position as the hole itself, like blank C, then the wheel and gravity eject the piece.   The eliminated parts fall through the hole into a pan or through another chute for delivery else-where.   Blanks that are positioned correctly, as at B, ride across the

hole and are pushed forward by the traction of the wheel. In cases where the chute is inclined, a jet of compressed air may be used for ejection, in place of the wheel.

This elimination principle is useful when the blanks are of such irregular shapes that one will not fall through the hole in a reversed position. If the blanks are of a shape that allows them to fall through the hole in either position, then they must be fed edgewise and reversed in the chute as described under Fig. 41.
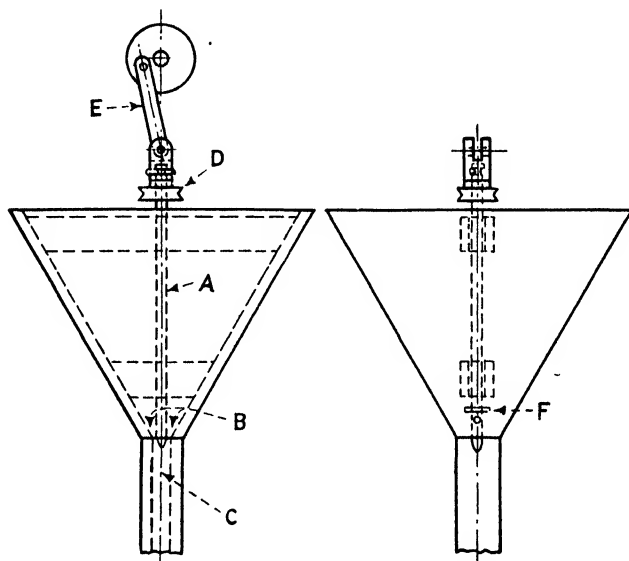

Fig. 43.—A hopper in which the vertical agitating pin *A* has both rotary and vertical movements. This action releases the work pieces at *B* so that they may freely enter chute *C*.

For shells that roll through a chute, in which the clearance width suits their lengths, the pieces that are misplaced by the hopper, with closed ends right or left, can all be eliminated by a reciprocating pin. The pin enters through the side of the chute. When a shell presents its closed end at the pin station, the advance of the pin ejects it, but the pin will enter the shell if the open end is presented. When the pin withdraws, the shell is permitted to pass on through the chute. All the shells that pass the pin are thus arranged with open ends in the same direction.

Hoppers with Vertical Agitators.—Conical and truncated pyramidical shapes of hopper heads can be made of thin castings, preferably brass. Some shops build them of cold-rolled sheet steel, or brass

plates; others use $\frac{1}{4}$-in. thick steel plates and assemble them with screws or by arc welding.

Figure 43 shows one of these types in which a vertical pin *A* is used to agitate and loosen small regularly shaped work at throat *B* and thus cause the pieces to drop into chute *C* in regular order.

Agitator *A* has two motions, rotary by means of driving pulley *D*, and vertical through crank arm *E*. At the top of the crank stroke, the throat of the hopper is opened to permit work pieces to enter the chute. Unless the pieces are very difficult to feed, the rotary feature is omitted. However, when the rotary motion is used, projecting pins are inserted at *F* to increase the agitation.
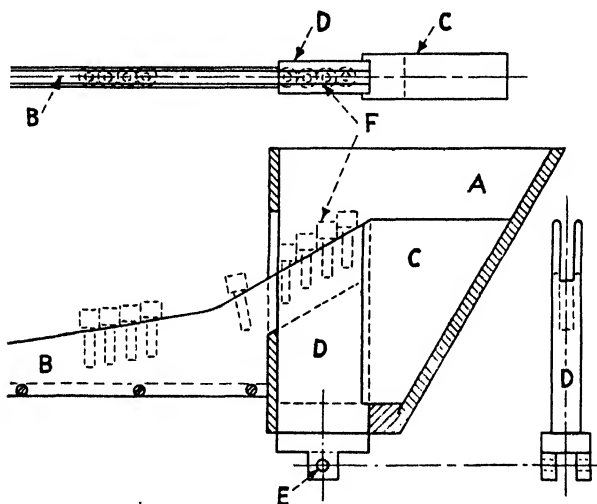

Fig. 44.—Hopper that delivers headed pieces, heads up, in a channel leading to a die or machine.

Stringing Pieces in Channels or on Rods.—Figure 44 represents a hopper principle applied in handling headed studs, screws, bolts, rivets, shells with external rims such as cartridges, and similar parts. The pieces must be delivered into dies or machines for assemblies or additional operations or for arranging them in packages.

The idea is to gather the parts rapidly from a large supply thrown haphazard into hopper *A* and to deliver them heads up in channel *B*. Partition *C* divides the hopper in two equal chambers. One edge of the partition is provided with a slot that guides the agitator slide and carrier *D*, as shown. The carrier has a 30-deg. angular channel across its top and is reciprocated vertically by a pitman rod which is attached at hole *E*.

At the downstroke of the carrier, the pieces roll, slide, and tumble into many positions relative to the channel opening in the top of the carrier; and when it ascends, several pieces enter the channel, as shown at *F*. At the top of the stroke, a shoulder on carrier *D* registers against the bottom of the hopper, causing the pieces to slide out into channel *B* by gravity. The hopper and carrier can be made wide enough to suit any size or condition of the pieces.

In most feeding devices having a hopper and chute that depend upon gravity to move the pieces, the vibration of the hopper mechanism and the vibration of the machine to which it is attached are "favorable faults"—and there are such faults in machinery—which help to move the pieces along and to accomplish desired results.

High-speed Automatic Feeds.—Quantity blanking and forming of sheet-metal parts has increased so enormously in recent years that considerable development work has been necessary with respect to mechanical feeds. These feeds are applied to both gap- and straight-side presses. Gap-frame presses operate at moderate speeds, but straight-side presses are often run so fast that the feed becomes the limiting factor. Inertia of the feed parts in being started from rest, moved a considerable distance, and brought to rest again in an instant of time tends, in extreme cases, to pound the feed to pieces or to cause inaccuracies and overriding which cannot be overcome by pilots or allowances in the dies. Press builders and manufacturers of automatic feeds endeavor to meet this situation by incorporating welded construction and hardened and ground alloy steels.

Automatic Roll Feeds.—These devices are made in two styles, single and double sets. The single-set type (Fig. 45) is employed when the material strip is heavy enough and stiff enough to be pushed positively across the die without buckling or where there is no scrap strip for an opposite set of rolls to grip. If the single set of rolls is used on the left side, they can pull the material across the die, if the scrap left from blanking is strong enough to prevent its breaking.

Drive to the feed rolls can be obtained either by a rack meshed with a pinion fastened to one of the rolls or by a pawl and ratchet. The operating lever is connected to a crank disk on the press crankshaft or to a slotted crank block. In either case by varying the crank throw in the slot, it is possible to vary the feeding length. Usually there is some kind of cam release on the rolls to allow the pilot pins in the press tool to register the strip just before blanking. The ram in descending trips a lever that releases or separates the rolls. The relief lever is also used to separate the rolls when inserting a new strip. Use of the relief is

advocated in all cases where pilot pins must register the strip from previously pierced holes.

Double-roll feeds are often set up with much accessory equipment, as Fig. 46 shows. Here a double rack and pinion roll feed is equipped with straightening rolls, a scrap cutter, an oiler for the stock, and an automatic centering reel.

In one installation, a double-roll feed was employed on a double-action cam press, in blanking and drawing cupronickel bullet jackets. This setup had a scrap winder on the left side of the press, making it possible for one man to tend several machines. The comparative
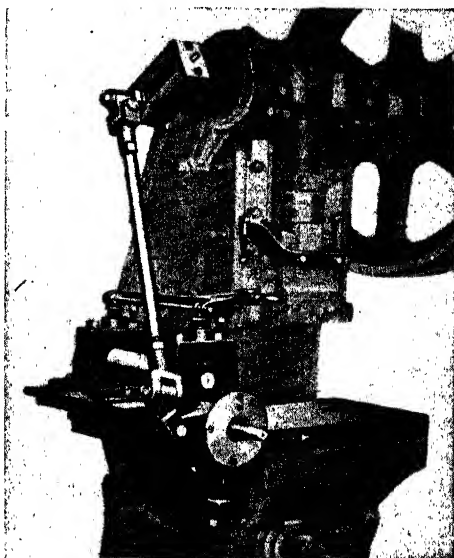

FIG. 45.—A pair of automatic feeding rolls at the left of the press pulls the material across the dies from the right, if the scrap is of sufficient strength to resist breaking. These rolls can also be used for feeding the strip from left to right. Notice the roll-release lever attached across the ram.

output of the press in 10 hr. with and without roll feeds is given as 25,000 and 13,000, respectively; enough, practically, to save the expense of one press and one man. Roll feeds of this type can be used on any type of gap press and can feed thin metal strips up to 500 ft. per minute or more. They can be purchased integral with the press or separately.

Any slight deviation in the feeding distance for which the rolls are set is cumulative, and we find ourselves eventually having too much scrap or else cutting into the hole left by the previous blank. This shows the need for roll relief which allows pilot punches to register in one or more holes of the work before blanking. The old types of roll-

feeding devices fed the rolls by a ratchet, but most of the present-day roll feeds are equipped with friction drives which are a decided improvement. The friction drive is more accurate and just as positive for feeding purposes.

Die Slide Attachments.—Although unfamiliar to many press users, such attachments have been in use for years. The attachment slides the die in and out of the press automatically but in synchronization
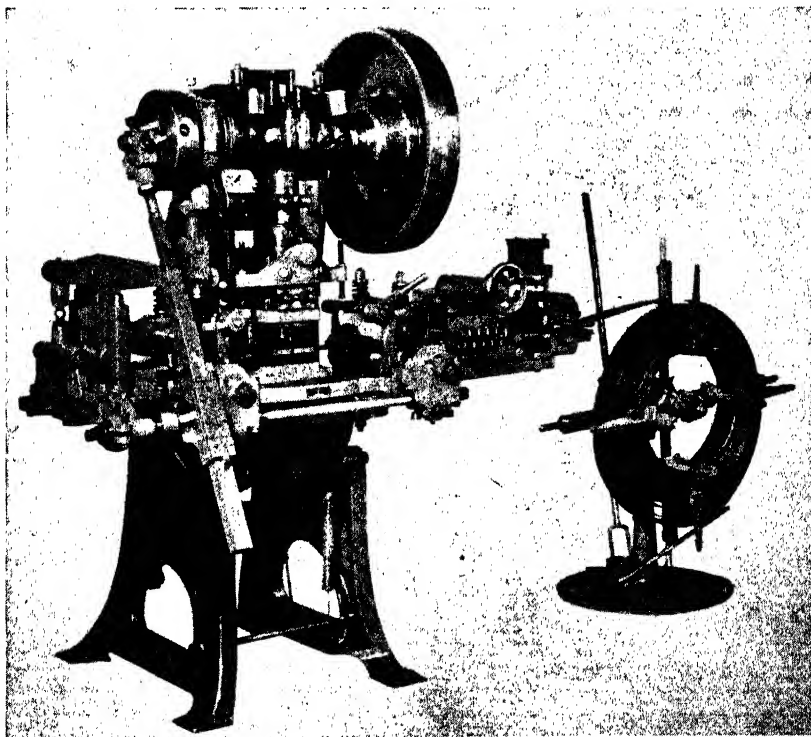

Fig. 46.—Either coil stock or strips can be fed by this double-roll automatic feed. This setup is intended for the general stamping shop having many different jobs to be run on one press. Accessories are a double rack and pinion roll feed, straightening rolls, scrap cutter, stock oiler, and automatic centering reel. (*Courtesy F. J. Littell Machine Company.*)

with the press stroke. It is primarily a safety device, and its use will sometimes increase production from 50 to 150 per cent, depending on the nature of the work. Another advantage is that the tools already in use on hand-fed presses can be attached with little or no alteration.

Tool setting is as simple as on a plain press, which makes this attachment suitable for small orders. Punches and dies are aligned by pilot pins which enter bushings in the die slide when the ram descends.

Knock-out cam
roll arm

Knock-out
connection

Roll connection

Gate knock-out
adjusting screw

Die-slide drive
bracket

Die-slide
arms (2)

Connection
arm

Pilots (2)

Pilot
bushings (2)

Connecting
links (2)

Die-slide
stop-screw

Bolster

Die-slide

Die knock-out
plate

Press bed

Die knock-out arm

Gate

Gate knock-out
lever

Gate knock-out
pin

Die knock-out
pin

Punch-holder

Die-holder

Guide plate

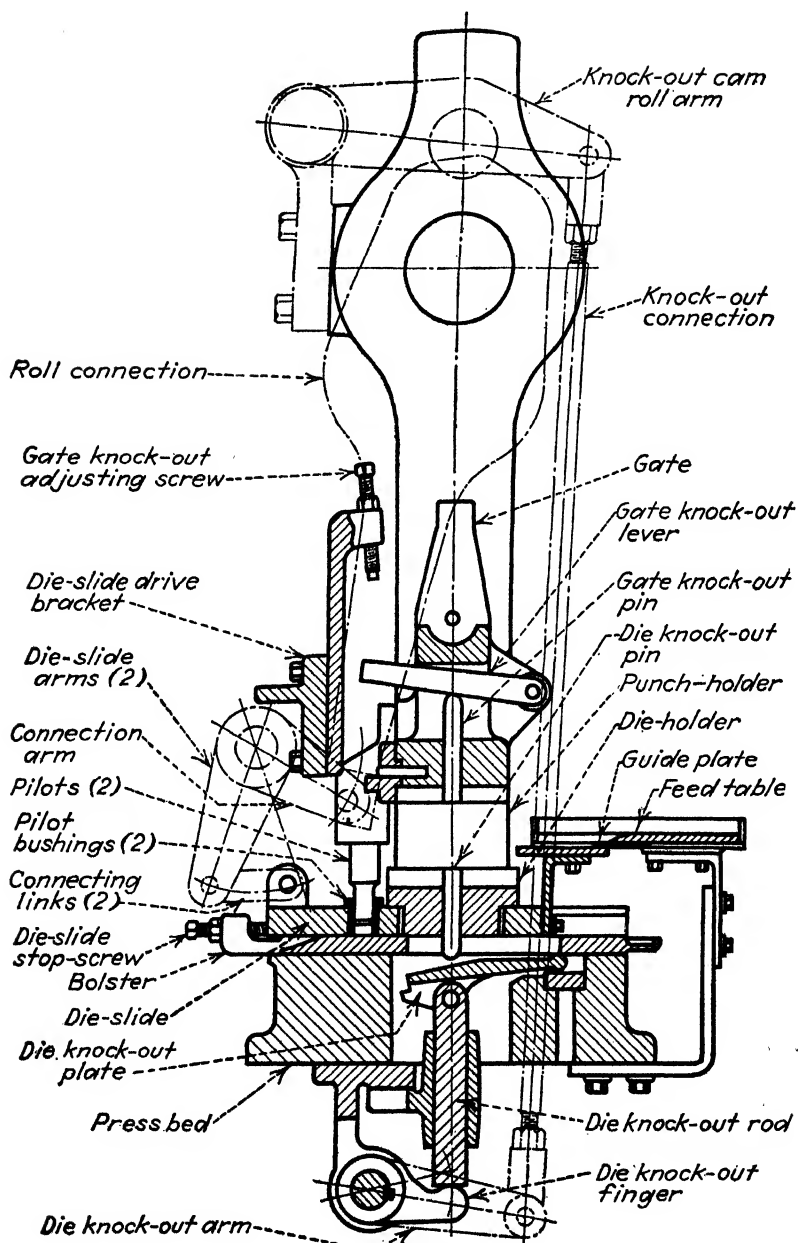Feed table

Die knock-out rod

Die knock-out
finger

Fig. 47.—This mechanism automatically slides the die into and out of the press for feeding. It increases production over hand feeding, because the die is loaded near the feed table, and it removes the operator's fear of injury. (*Courtesy Waterbury Farrel Foundry & Machine Company.*)

A cross-section view showing the working members of this attachment and its principle of operation is given in Fig. 47. For work that has a tendency to cling in the tool, die knockouts and ram knockouts are employed.

Automatic Slide Feed.—The feeding unit illustrated in Fig. 48 is mounted on an adjustable floor stand to suit the height of the press. It is suitable for feeding flat strips, round sections, or other shapes than flat. This unit will feed coiled stock to presses on exact centers regard-
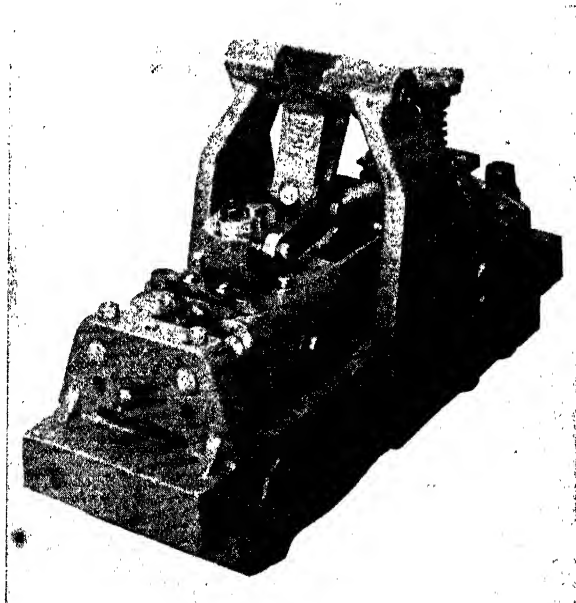
FIG. 48.—A reciprocating slide confined between two positive stops is the principle applied in this automatic slide feed for high precision feeding. (*Courtesy U. S. Tool Company.*)

less of commercial irregularities in the stock. Its great accuracy is based on the principle of a confined slide which reciprocates between two positive stops. The stock grip is mounted in the slide and operates by the "jack-knife pinch" principle, which is positive. It is actuated by an eccentric on the crankshaft, connected by an arm to the rocker lug shown at the top of the view. There is a lever provided for opening the stock jaw to admit the end of a new coil. It has a brake that prevents "strip throw" and an adjustable "drag" that holds the advanced strip.

Vertical Magazine and Horizontal Slide.—A horizontal sliding feed (Fig. 49) is operated by a compound linkage in the rear of the press.

The linkage is attached to a horizontal rocker shaft, which extends between the press frames and has a bearing in each frame. The slide, linkage, and shaft are operated by a slotted connecting arm, with the slot attachment to an eccentric on the crankshaft. Stroke of the slide is adjustable.
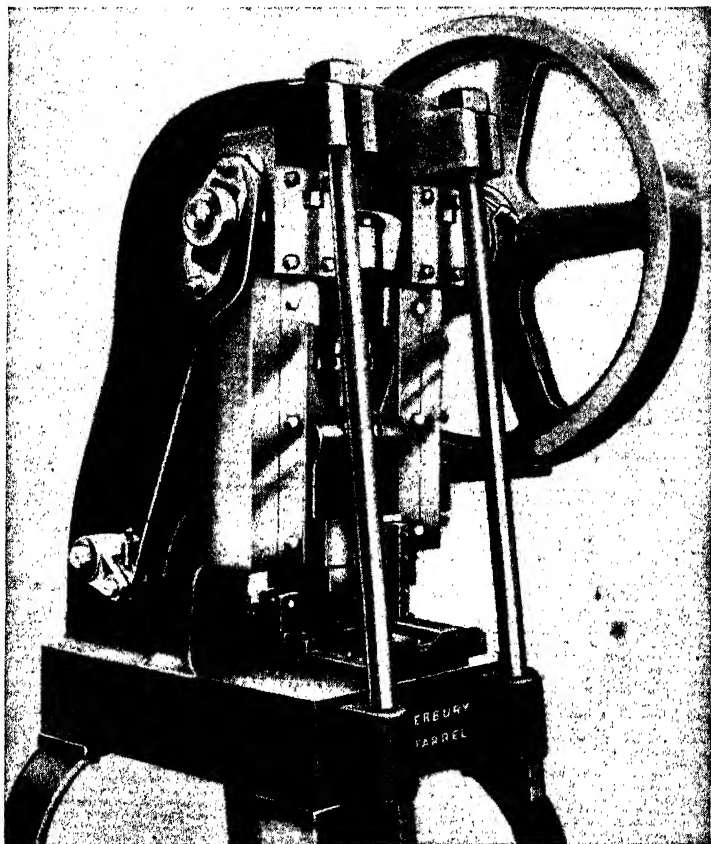

Fig. 49.—Blanks placed in a vertical magazine at the front of the press are transferred to the first operation tools by the horizontal slide shown beneath the magazine. The slide then transfers the work to a second operation after the first operation is completed.

Blanks are fed into a vertical magazine shown at the front of the press and are then transferred by the slide to the first-operation tools. The pieces are then held by two pairs of spring carrier fingers in the slide, while being transferred to a second operation. The slide is also provided with "pull-off fingers" which strip the finished work from the punches.

Transferring Shells.—Another feed is the horizontal progressive blade feed used on multiple drawing presses. These presses may have several rams, five being the usual limit. In average practice, drawn cups are fed to a continuously revolving friction dial, from which a finger controls their entrance to the first die. Running the full length across the dies are two parallel horizontal bars having V-shaped notches on their inner edges at each die. When the ram descends, these bars are separated by the punches. As the punches ascend, the knockouts bring the bottoms of the cups up level with the top of the dies. The two bars close together by spring action and hold the shells in the V-notches and then move forward one station. This operation is repeated at each stroke, with one shell feeding in and another leaving the press finished. The V-notches, of course, must fit the diameter of the cup at each station.

Hitch Feeds.—Another feeder is called a "hitch feed." It is designed for handling light-gage strips up to about 3 in. wide. It is attached on the right end of the die holder for right to left feeding; and $1\frac{1}{2}$ in. is left open on the end of the die holder for attaching. It is operated by an angular lug secured on the punch holder. When the ram descends, the angle on the lug contacts a roller on the feeding slide, causing it to recede for the next throw. A "pinch check" against the strip holds the stock from slipping back while the jack-knife grip in front of the check takes hold. When the ram ascends, a tension spring attached on the feeding slide pulls the slide forward with the strip a distance equal to the blanking centers of the die. The angle and width of the lug is designed to suit each job, but this is a very simple layout.

Automatic Hitch Feed.—In blanking dies where a scrap frame passes out, a hitch feed can be made a functional part of the tool. Automatic stops are then unnecessary. The principle is presented in Fig. 50, and the operation is shown at the bottom of the press stroke. A simple operating mechanism consists of a horizontal cam sliding between guides. This cam is positioned parallel with the work strip at the left of the die and beside the upper edge of the strip.

A "hook feed" is attached by a fulcrum screw to a block secured at right angle across the horizontal cam. A flat spring forces down the tooth on the hook so that it slides on a plane coincident with the die-block surface. The hooked tooth engages over the "bridge" in one of the blanked holes of the scrap. When the ram descends, the vertical cam enters a slot in the horizontal cam. A 45-deg. nose on the vertical cam pulls the hook and strip toward the left equal to a distance of one blanking center, or B/C. This movement exposes an uncut portion of the work strip to be pierced and blanked. Meanwhile, the vertical

cam locks the hook in place, by entering a dwell space A, which occurs just before blanking.

When the vertical cam ascends and the work material is stripped, a compression spring causes the horizontal cam to advance toward the right until the tooth engages the next scrap bridge. This occurs when the left edge of the slot in the horizontal cam begins to ride on the dwell space B of the vertical cam. Although the rise on the vertical cam nose is 45 deg., in this case it is obvious that its run is also equal to the B/C.
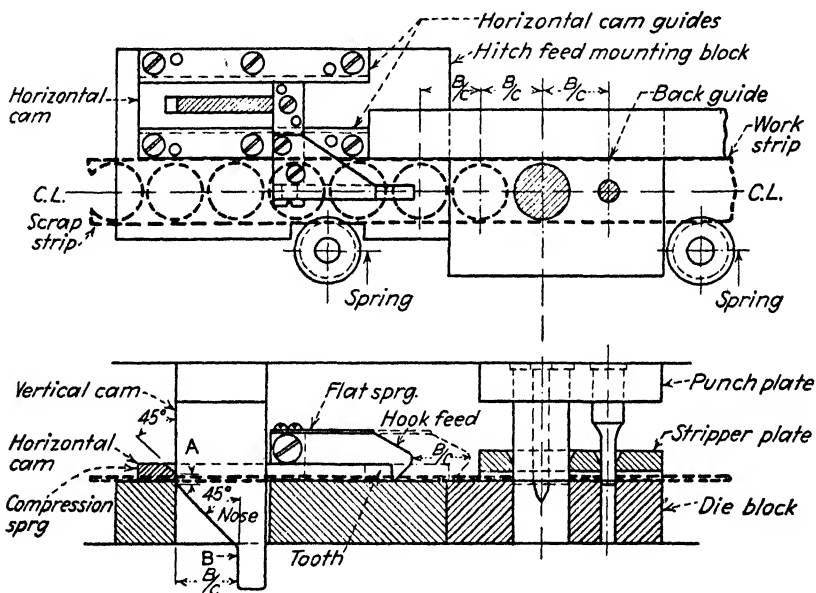

Fig. 50.—A hook feed, positioned at the left of the die, is actuated by a vertical cam attached to the punch-holder, and no automatic stop is needed.

A brake to prevent overfeeding consists of two spring rollers. These ride against the front edge of the work strip, as shown.

Dial Feeds.—The applications for this feed, if a little ingenuity is used, are almost without number. They include redrawing, piercing, notching, stamping, broaching, wiring, burring, bending, and many other simple operations. The feed can also be used for multiple operations such as riveting and assembling two or more parts. In performing operations at more than one station, it is advisable to balance them so that the punch strain will not be excessive on either side of the ram. Dial feeds can be made fully automatic by attaching a combination chute and hopper for feeding shells or other parts to a dial, as shown in Fig. 51. This arrangement is justified when the

output is sufficiently large. Dial feeds are best suited to the single-crank gap-type presses but are sometimes used inclined when the work is suitable for ejection behind the press.

In operation, the work pieces are placed in duplicate stations on the face edge of the dial; they are then indexed with the dial and halted under the punch for operations. The work removal occurs at stations beyond the die, by using vertical ejector pins operated from underneath or by a side-action cam or by arranging a "flip-off" finger over the dial.

It is possible to eject certain work through its nest in the dial by the descent of a vertical finger. The dial and work are indexed beyond
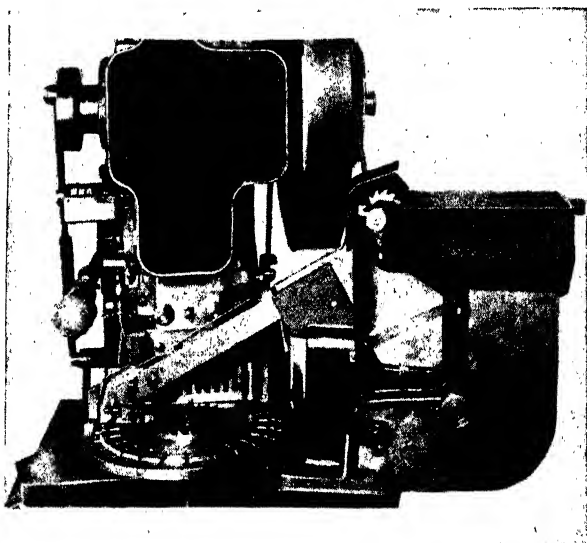

FIG. 51.—Circular dial feeds can be made fully automatic by attaching a combination chute and hopper.

the die, one or two stations, and over a clearance hole through the die shoe. The finger, in descent, is then in vertical line with the work, the nest, and the clearance hole; this method of work removal is simple when conditions in the tool design can be made favorable for using it.

A positive lock is necessary for holding the dial stations at punching centers. This is accomplished in several ways. One method is to attach a spring-compression pilot pin in the punch holder; the pilot, in descent, enters a bell-mouthed shouldered bushing in the dial and locks it in position.

Hand-fed Dials.—In using this type of dial a serious difficulty arises. The operator may fail to index the dial fully into the next

station; and when the ram descends, the punch wrecks the dial, the tool itself, and perhaps the press. To avoid this, the clutch must be operated either by a mechanical control or by a limit switch used in conjunction with the movement of the dial. This control, placed at the circumference of the dial and in contact with a suitable cam face, prevents tripping the clutch unless the dial is correctly positioned with a station directly under the punch.

Hand-fed dials are locked in operating position by the descent of spring compression pilot pins ahead of the punch, which enter large bellmouthed shoulder bushings positively located in the dial disk. These pilot pins will relocate the dial and work ahead of the punch descent, even though the work station is erroneously positioned $\frac{1}{4}$ in., or more, either way.

Friction Cartridge Dial.—This dial is simply a plain steel disk fastened to the flat face of a bevel gear by which it is driven. The
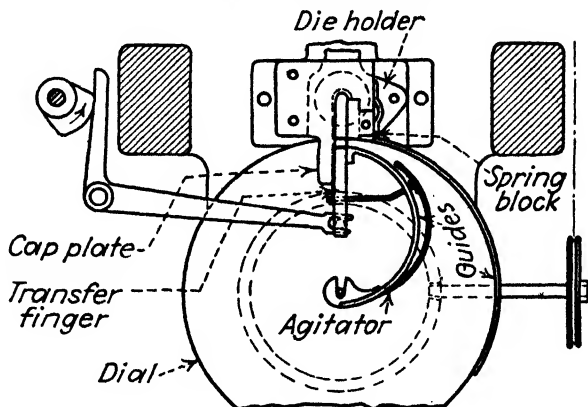

FIG. 52.—A belt-driven friction dial is applicable to redrawing shells; the shells are carried between rear guides, and thence to the dies, by means of a transfer finger.

gear revolves on a vertical stud in the dial bed, the latter being attached to the press bed, and is easily removable, together with the dial.

Although this equipment is used largely for redrawing and sizing cartridge shells in the munitions industries, it is also a general-purpose tool. It is readily adapted for redrawing or other secondary operations, on shells that have a flat bottom of sufficient diameter to stand upright on the face of a slowly revolving dial.

This friction-dial mechanism is applicable to any single-action gap-frame press. Its construction and operation are diagrammatically illustrated in Fig. 52. Here it is seen that the dial is driven by a round belt and bevel gearing. The dial is continuously revolved. Shells are placed on the dial, closed ends down, and are carried in between two guides. They pass to the rear of the dial

and are prevented from clogging by the action of the agitator shown. After leaving the guides, the shells are carried in to the dies by a transfer finger. This finger is actuated by a spring and is positively returned by the cam shown at the left.

The dies are located in a holder attached to the die bed, which can be swung to the rear for replacements. A cap plate on the die holder guides the work and enables the transfer finger to locate the shells directly over the dies. A spring block on the cap plate exerts tension on the shell and thus prevents it from tipping while being transferred over the center of the dies. The dies are in pairs and placed one above the other in the holder. They are a floating fit in a bushing provided in the die holder. The upper die is for the first draw, and the lower is for the second draw, or sizing operation.

Duplex Friction Dials.—Such equipment is of special construction for redrawing and sizing ammunition shells in great quantities. They are built into a special duplex press for that purpose. The press has two cranks and rams which operate in vertical slides standing side by side. Two sets of tools are used in each press, stripper plates, special double guides, and special carry-in fingers which hook around two shells and transfer them in pairs to the dies. This type is used only where the shells are of uniform size and when the requirements are large enough to justify the expense.

Auxiliary Dial.—This is a friction-driven dial and revolves continuously. It is mounted in front of the ratchet dial and in the same plane with it. It is used in feeding shells, or other work, into the passing stations on the ratchet dial. Shells are placed on the friction dial with closed ends down. The friction dial arranges the shells in a single line and feeds them, one at each station, as explained under Fig. 51. The carry-in lever is actuated by an extension of the regular pawl slide at the left of the ratchet dial.

Two-operator Dials.—When two or more parts are fed to a dial for press assembling, a large dial is often employed, about 20 to 28 in. in diameter, as in Fig. 53. The extra size provides places for two operators in front of the dial. An example is one in which rubber eraser tips are pushed into their cap shells in the manufacture of mechanical pencils. The first operator, at the left of the press, places the metal caps closed ends down, in the passing dial stations, while the second operator, at the right, places the eraser tip in a guide over the open ends of the caps. In passing under the ram, the punches in descent assemble three eraser caps per press stroke.

Dials for Notching Stator and Rotor Laminae.—Two types of mechanisms are used in feeding these dials: a ratchet mechanism and friction feeds. Friction feeds are operated as follows: A friction

band, lined with leather, driven by a crank and connections from the crankshaft, grips the circumference of the dial and indexes it forward. When the feeding direction of the band is reversed, a locking pawl drops into position and holds the disk stationary during the lower part of the press stroke, or while the punch and die are working. The blanks are positioned on the dial, and then the clutch treadle is "stepped."
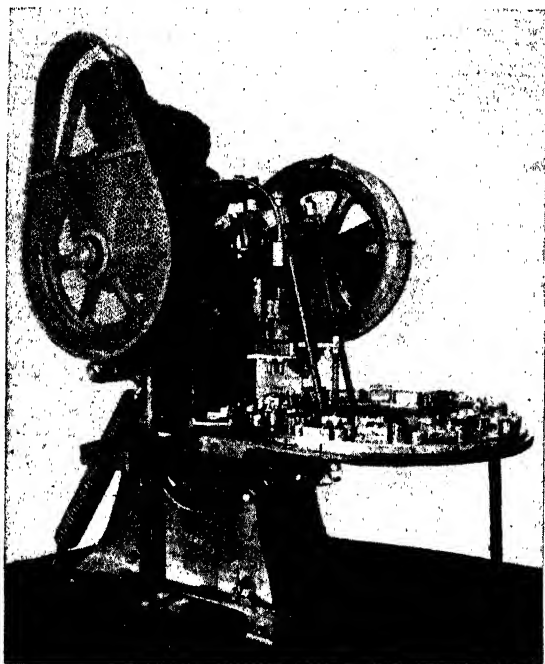

FIG. 53.—In this large circular dial setup, several parts can be assembled at each press stroke. Two and sometimes three operators load the parts into stations as the dial revolves.

The dial rotates in automatic conjunction with the ram until the correct number of notches have been cut by circular rotation. An automatic "releaser" stops the machine and frees the work, which is then removed.

The ratchet type of feed is illustrated in Fig. 54, and the feeding mechanism is plainly shown at the left side of the press in the foreground. This machine and the one shown in the following illustration are Ferracute presses. In Fig. 54, there are four sections in each complete circle of rotor laminae, with 120 notches cut in each finished piece. This setup is designed to finish 1,350 complete laminae in 8 hr. which means that the operator must handle 5,400 pieces twice every day.
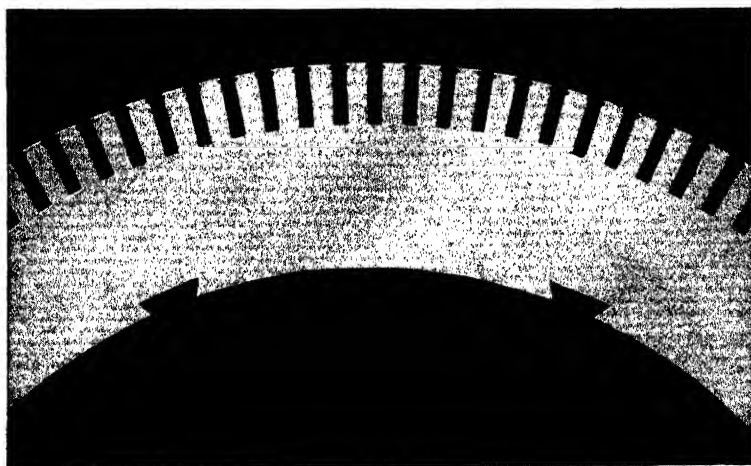
Fig. 54.—Exterior notching of rotor laminae on a dial press, and a sample section of
the work produced.

Figure 55 shows another type of press and dial for the internal notching of a stator lamination. When equipped with a suitable ratchet and properly adjusted, it is necessary only to locate a blank disk in place and start the machine, which will then make strokes

Fig. 55.—Interior notching of stator laminae on a dial press. These machines are also used for notching ball-bearing retainers, oil stove burners, and similar parts.

corresponding to the number of teeth in the circumference of the ratchet wheel and automatically stop. Medium-sized work, having 20 or more notches, may be finished at the rate of 400 strokes per minute. The ease and safety of handling this dial is indicated by the fact that the operator in the picture is blind.

CHAPTER IX

PRELIMINARY STEPS IN DIE ENGINEERING

For Maximum Efficiency, the Die Engineer Should Have a Knowledge of Press-tool Nomenclature, Layout Methods, Tool-quality Grades, the Approximate Costs of Dies, Hourly Output, and the Probable Cost of the Finished Products

Introduction.—In engineering offices where large dies are designed, it is customary to refer to the die holder and its attached parts as the "lower die" and to the punch holder with attachments as the "upper die."

The word "die" has a double meaning; it may refer to the entire press tool or only to the individual die block or sections that carry the shape or outlines of the work. "Die block" is probably a better name for the individual block, and "die sections" for the blocks in a sectional die. Using these terms avoids confusion of names and favors clearness of expression. The terms die block and die sections, as defined, are so employed throughout this book. A complete tool, as used in a punch press, will be called a "press tool," but at times it will also be called a die.

Dies for Automobile Bodies and Parts.—Specifications often used in viewing dies for drawing and forming automotive body parts are "drawn on car line" and "drawn off car line." When it is possible to finish a piece in the die on a plane parallel with its final assembly in the car, the tool is said to be "drawn on car line." On the other hand, for drawing a die "off car line" the number of degrees of arc are specified which indicate the angle to which the work must be tilted from its normal position in the assembled car to clear the forming and drawing punches when these members enter the die.

An example of a die drawn off car line would be a forming and drawing die for producing a highly streamlined fender having a drawn-over front that would obviously interfere with the forming and drawing members of the tool, unless the opposite end of the fender is elevated a number of degrees away from its normal car-line position.

Drawing and Detailing of Dies.—In first-class die drawings, piece parts are not detailed on assembly drawing sheets; details belong on secondary sheets. The dimensions given on the assembly drawing are

general.   Give the available tool area of the die set represented by its length and breadth.   Give the diameter of the punch shank; but if a punch shank is not used, give the size and location of the bolt holes through the die shoe and punch holder for securing the die in the press.

When no punch shank is used, it is often found necessary to bore two "setting-up holes" through the die shoe; these must coincide with entering pins in the bolster plate.   Especially is this true in cases where the die must be exchanged with other dies and still be positioned correctly relative to feeding rolls, the rolls being in fixed positions at either one or both ends of the die.   Setting-up holes are usually bored in the diagonal corners of the die shoe and of diameters for an easy fit over the pins.

Detail numbers are assigned to each separate die part and should correspond to the numbers given later in the material list on the assembly sheet.   Finished parts are dimensioned $\frac{1}{8}$ in. under the commercial sizes of rough steel which allows sufficient material for machine finishes.   Where a part of a hole is cut into one edge of a block, the stock ordered should include the full diameter of the hole. The part of the hole not wanted is machined from the block after boring the hole.

Drawing the Die in Closed Positions.—Most dies are drawn in closed positions, which is at the downstroke of the press with the work finished.   The closed height should be given, and usually the thickness of the die shoe and punch holder and the length of guide posts.   The closed height of a press tool is the distance from the top surface of the punch holder to the under surface of the die shoe when the tool is shut. It must not exceed the maximum die space of the press.   The maximum die space is measured from the face of the ram to the surface of a standard bolster plate, when the press stroke is down and the screw adjustment above the ram is fully screwed up.

If the closed-tool height is greater than the maximum die space of the press, this error may be corrected by reducing the thickness of the upper or lower members of the die set or by using a bolster plate of less than standard thickness.   To reduce the closed-tool height by using any other subterfuge may sacrifice the utility or working life of the tool.   If none of these changes can be made, it will be necessary to use the tool in a larger press having a greater die space.   Such a press has fewer strokes per minute, and the output would therefore be considerably reduced.

Initiating the Drawing.—If the design is not "a repeater," meaning one often made before, and if the tool must perform one or more unusual operations, it is advisable to begin the design with preliminary

tryout sketches. Lay out in red the blank or the proposed series of operations. If the work is comparatively simple, make freehand sketches; if it is rather complicated, draw it to scale. If the part to be made is very small, draw it five or ten times full size. Large work can be scaled down to half size, but usually the individual tool parts are detailed full size, if possible. To enlarge a drawing five sizes quickly, lay it out ten times full size, using a half-size scale. Develop the design from the center of the piece toward the outside.

Draw the tool-steel members first, and then add a sketch of the die set. Transparent templets of standard die sets are used by laying them over the drawing. When the proper size of templet is found and positioned, scribe a line around its edges.

Most drafting offices have the recent printing equipment for making positive black-, brown-, or red-line prints on white backgrounds. Red-line prints can be used to advantage when initiating the design for a new tool or machine. Make a red-line print of the proposed work, and then lay out the tool or machine around it.

Another advantage in using this method is that many changes by erasures can be made without removing the indelible red lines in the print. When the design is satisfactory, make a tracing of the combined work and tool for an assembly drawing, preparatory to rendering the details.

Viewing and Drawing the Assembled Die.—The assembly drawing for ordinary press tools should present at least two principal views, the lower die plan and the front elevation. In unusual designs three or more views are sometimes necessary. The lower die plan is the upper left-hand view. In this view, the surface of the blocks on the shoe is shown, and the upper die is omitted for clarity. If a plan view of the upper die is necessary, it is customary to show it at either side of the lower die plan. Show the upper die holder as having been lifted from the lower die and turned face up (revolved 180 deg.) from the direction in which it was lifted.

The front elevation is drawn below the lower die plan; this is a view of the tool as seen on the press in front of the operator. The importance of making the front elevation represent the operator's view cannot be overstressed; in many dies the working principle and parts are difficult to explain or to understand if this usual standard is neglected. Three views of a die as just described follow.

Figure 56 illustrates a die used in a tractor plant for blanking part of a container. This drawing is a good example of a compound sectional die. There are nine sections in both the upper and the lower die members. Fifteen small holes and one elongated slot are cut
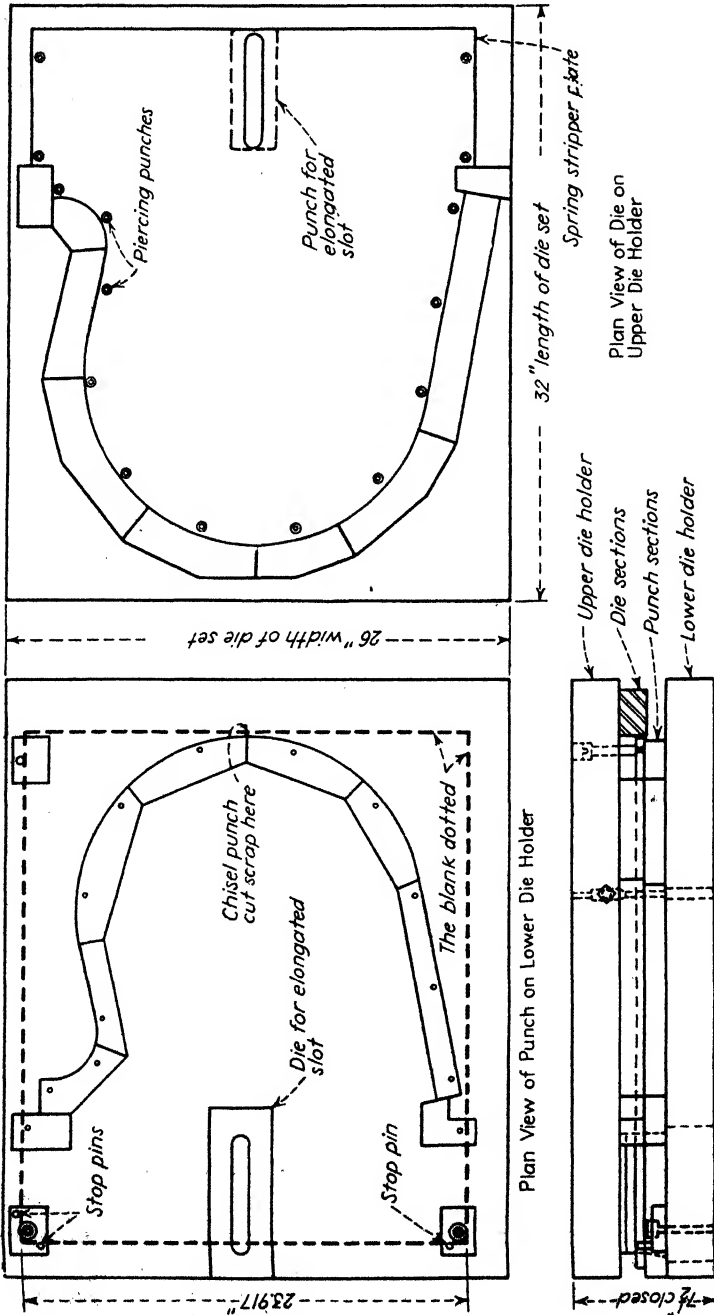
Piercing punches

Punch for elongated slot

Spring stripper plate

32" length of die set

26" width of die set

Plan View of Die on Upper Die Holder

Stop pins

Stop pin

Chisel punch cut scrap here

Die for elongated slot

The blank dotted

23.917"

Plan View of Punch on Lower Die Holder

Upper die holder

Die sections

Punch sections

Lower die holder

Front Elevation

7" closed

FIG. 58.—Die drawings should show the plan of the die holder in the upper left-hand corner and the front elevation of the completed tool below. The plan of the upper die holder can be turned face up, at the right of the die plan.

simultaneously with the blank.   A rectangularly sheared cold-rolled steel blank $\frac{1}{16}$ by 24 by 27 in. is the work material.   The blank is positioned over the lower die, or punch, against the four stop pins shown.   This tool is considered a large one in shops doing light manufacturing.   The spring stripper plate shown within the die is torch cut to shape, and the edge is subsequently rough ground for a loose fit inside the die opening.

If the working relationship between punches, die blocks, pilots, shedders, spring pads, ejectors, guides, feeds, stops and gages becomes clearer by showing additional right- or left-hand projections of the plan, these should be made.   The views should not be crowded or approach the border of the sheet less than 1 in.   These precautions indicate that foresight is necessary in planning the drawing unless the design is a very simple one. Preparatory sketches should be roughly plotted to scale from preliminary freehand. sketches; this procedure determines the size of the views and thus enables one to plan his assembly and to choose the proper size of drawing sheet.

In rendering die drawings, sectional views are more frequently employed than in drawings for other types of tools and machines.   The front view is usually a section taken on a vertical plane through the horizontal center line of the die plan.   Sectional views show the important interior construction upon which the final success of tools so much depends; this information is invaluable
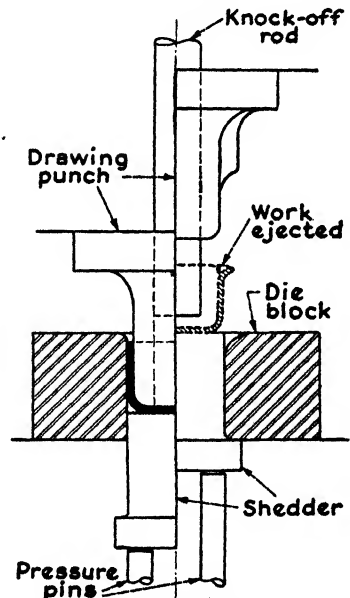

Fig. 57.—Press tools are ordinarily viewed in the closed position, but exceptions must be made for clarity.   When a closed position of the punch obscures important features of the die, the punch is divided, one-half being shown *up* and the other half *down*.

in the die shop where the responsibility rests for producing satisfactory tools.

Perforating and blanking dies are shown closed, especially when followed by forming or drawing operations in the same die.   The relative lengths of the punches are thus accurately found—an important determination.

In viewing a combination blanking and drawing die, the front elevation is always shown closed.   The usual practice is to show a

vertical section passing through a plane coincident with the horizontal center line of the completed tool. Relative sizes of the cutting and drawing members are thus easily determined.

Press tools are not viewed in a closed position if legibility of the die parts is sacrificed. This condition is sometimes encountered in viewing the front elevation of certain forming and drawing dies where a deep closed position of the punch might obscure important features in the die. In such cases it is best to divide the punch on its vertical center line and show half the punch *down* at the completion of the press stroke, while the remaining half is shown in ascent above the die entrance. Figure 57 is an example.

Press-tool Standards.—A loose-leaf book of tool standards is a timesaver for the Tool Engineer. The standards usually comprise all types of die sets that are not commercial, the space and dimensions for attaching feeding devices, chutes, magazines, air cushions, spring-pressure pads, and all other standard devices used in that particular shop. The standards should include the method for dimensioning dies and the dimensions for presses in regard to the length, breadth, and thickness of bolster plates, size of openings through press beds, the size of punch shanks, minimum die spaces, the screw-adjustment distance for the ram, and the press tons capacities.

The general rule for tool dimensions that affect the product is a tolerance of plus or minus 0.005 in. on common fractional dimensions and plus or minus 0.001 in. on decimal dimensions, unless otherwise specified. Close tolerances are difficult to reach and to maintain and should not be used unless absolutely necessary.

Tolerances should be as large as the accuracy of the work permits. Close tolerances should be questioned, if by using them tool costs are increased and output is restricted. Too many designers fall into the habit of specifying close limits just to play safe. Tolerances of omission instead of those of commission may cost more later in the assembly departments. This fact points the way toward making a thorough investigation of the probable assembling difficulties of the product before deciding to use or to omit tolerances.

Tolerance and Allowance Defined.—The words "tolerance" and "allowance" in reference to varying dimensions are erroneously used interchangeably; these terms have entirely different meanings. The American Standards Association defines "tolerance" as the amount of variation in the size of a part and "allowance" as the minimum clearance space between mating parts. When the mating parts are equal in size, the clearance space is zero allowance. The

allowance is negative in all cases from the closest fit possible to assemble by hand, up to and including heavy forced and shrink fits.

There are eight classes of fits and allowances: (1) loose fit, large allowance; (2) free fit, liberal allowance; (3) medium fit, medium allowance; (4) snug fit, zero allowance; (5) wringing fit, zero to negative allowance; (6) tight fit, slight negative allowance; (7) medium-force fit, negative allowance; (8) heavy-force and shrink fit, considerable negative allowance.

In practice, minimum and maximum tolerances are specified for each of two mating parts that will provide the desired allowances between them. Figure 58 presents a problem in tolerances and allowances for a medium fit. The plug must fit the hole with a minimum allowance of 0.002 in., the maximum allowance being 0.004
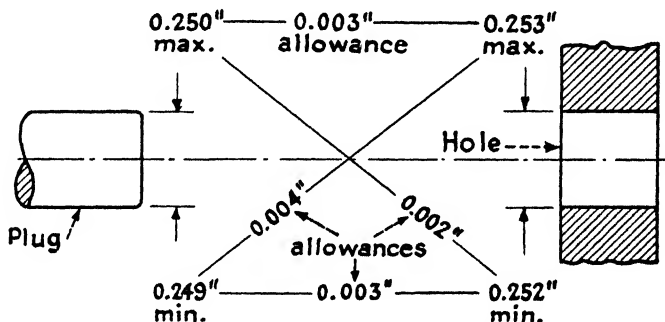
Fig. 58.—All conditions of allowances between a minimum of 0.002 in. and a maximum of 0.004 in. are shown at a glance for the dimensions given of the plug and hole.

in. The diagram shows at a glance all the variable allowances that may occur in this case. There are other dimensions that fulfill these conditions, such as 0.252 in. maximum and 0.251 in. minimum for the plug and 0.255 in. maximum and 0.254 in. minimum for the hole. The dimensions usually start from the commercial size of the plug material.

CLASSIFICATION OF PRESS-TOOL GRADES

Dies are divided according to quality into about four general classifications. Some manufacturers classify the grades of dies into more than four divisions. The number of classes depends largely on the diversification of work to be performed.

Class A Dies.—These embody the highest grade of workmanship and materials and must give maximum service for large and continuous production. This grade includes hardened, ground, and lapped

guide posts and bushings, automatic stop, and finger stops when necessary. The die block must not be less than 1 in. thick, and the cutting members must be within limits of ±0.001 in. where required.

The die must have a $\frac{1}{4}$-deg. taper for its entire thickness or be straight for about $\frac{1}{4}$ in. from the top; die to have hardened steel bushing holes where possible. Stripper plate must be machine steel, fitted closely to punch, and have hardened-steel bushings for all small perforating punches where possible.

The blanking punch must be solid with a flange, and the perforating punches set in a punch plate. Blanking and perforating punches are to be provided with spring push-off pins where possible. Perforating punch heads must have hardened steel backup disks. Perforating punches that are less than $\frac{1}{4}$ in. in diameter shall be placed
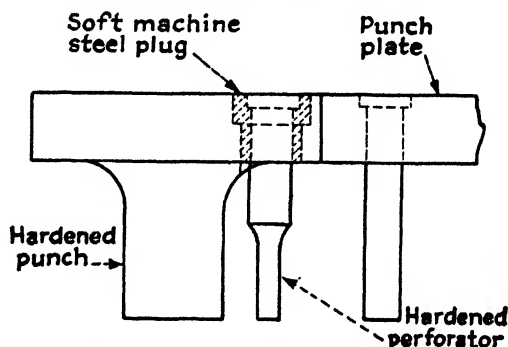
Fig. 59.—A perforating punch, close to a large punch, can be secured within a soft steel plug inserted in the larger punch flange; the perforator can thus be located accurately, even though the hole in the flange is distorted after hardening.

in hardened quills when possible. Dowel pins and holes are to be ground and lapped. Clearance between punches and dies and the alignment of all cutting edges shall be such as to produce smooth blanks free from burrs.

In high-grade dies, perforators near a larger punch are secured by soft steel plugs in the punch flange as shown in Fig. 59. Sometimes this condition is unavoidable, and the flange is made to serve as the punch plate. The advantage of using this method is that the perforator can be accurately located even though the counterbored hole in the flange has become distorted or has changed in position after hardening. A similar method is used for locating guide posts and guidepost bushings in die shoes and punch holders that are hardened tool steel. The soft steel plugs are press fitted in suitable holes in the hardened upper and lower die set members before boring the guide post and bushing holes.

Class B Dies.—Such dies have high-grade workmanship and materials suitable for producing work of average or medium quality and must give long service for large production. This grade includes hardened and ground guide posts and bushings, automatic stop, and finger stops when necessary. The die block must not be less than $\frac{7}{8}$ in. thick, and the cutting members must be within limits of ± 0.002 in. where required. The die must have $\frac{1}{2}$-deg. taper for its entire thickness. The remaining specifications are the same as those for Class A dies.

Class C Dies.—These dies have the following specifications: plain punch and die holders; plain flat or pin stop; die block not to be less than $\frac{11}{16}$ in. thick, and the cutting members must be within limits of ± 0.003 in. where required. The die should have $\frac{3}{4}$-deg. taper for its entire thickness. Stripper plate must be machine steel and not in contact with the punch or perforators. The punch is to be set in a steel plate or screwed to the punch holder; perforator bushings to be set in the die block when possible. Clearance between the punch and die should be such as to produce fairly smooth blanks, but small burrs are permissible. The general appearance of the die is not important, and refinements are not necessary.

The foregoing specifications apply to all classes of dies including blanking, blanking and perforating, progressive, combination, and compound dies.

Temporary Dies.—These dies should embody first-class workmanship and materials but because of small production requirements should have the following features: plain punch and die holders; plain flat or pin stop; die to be $\frac{1}{2}$ in. or less in thickness, according to requirements; cutting members to be within ± 0.005 in., or more if specified; die block to have $\frac{3}{4}$- to 1-deg. taper; stripper plate to be thin machine-steel plate with strips underneath to form a guide for the stock; the plate should not contact the punch or perforators. The punch and perforators should be short and set in machine-steel plate on the punch holders or held with setscrews or other inexpensive means. Blanks produced in this die should be fairly smooth, but small burrs are permissible. The general appearance of the die is unimportant, and refinements are not necessary; machine finishing the parts is required only where necessary to make a fit.

Cost and Upkeep of Dies.—In manufacturing concerns where the product is composed largely of sheet-metal parts, the die expense and maintenance are several times the cost of tools for drilling and milling; in fact it is more than all other tools combined. This expense is offset, however, by the ease and speed with which well-designed dies

will continuously produce duplicate parts in great quantities. The approximate cost and upkeep of dies and the cost of the output are important factors to be aware of when beginning a new die design. Good tool engineering is shown by knowing the grade of tool required, the proper specifications of tolerances, and whether or not the expense of making tool drawings is advisable.

The toolmaking expense may be ascertained fairly closely, from the cost cards that show the expense for similar tools made at a previous date. If such cost cards are not available, then the cost for each part should be estimated separately, and the cost of final assembly and for testing the die should be added.

Diemaking costs often depend upon the skill of the diemaker and the efficiency of the machine tools that he uses. Some manufacturers prorate the overhead expense on the basis of the previous years' operations. The overhead expense varies in different localities, but it should be definitely known and included in estimates.

For accurate material costs, the cubic-inch contents of each member of the tool in the rough are computed and multiplied by the weight of the material in pounds per cubic inch, times the price per pound. Tables of weights per inch of length for standard sections of steel are available for making these estimates. If your shop sends out its die steels for hardening, the cost of hardening per pound should be included. If the die set is a commercial one, the price, less discounts, is taken from manufacturers' catalogues.

Cost of Work Produced in Dies.—The weight in pounds of material necessary for blanking 1,000 pieces is computed by multiplying the area, in square inches, of the material used for one blank by 7.3 times the weight of the raw material per square foot. This formula allows 5 per cent for waste ends. To find the area in square inches for one blank, multiply the width of strip in inches by the blanking center distance in inches.

When a press is fed by hand, only 40 per cent of the total number of press strokes are utilized. If an automatic roll-feed attachment is used, more than 80 per cent of the strokes are used. The following formulas are useful for computing the labor and material costs per 1,000 blanks. For hand feed: $T = (S \div 0.024\ N) + M$. For roll feed: $T = (S \div 0.048N) + M$. In the foregoing formulas: T = total cost of labor and material per 1,000 blanks; S = operator's hourly wage; N = number of press strokes per minute; and M = material cost per 1,000 blanks.

For bending, drawing, and forming die operations, the cost of production can be closely approximated by using a stop watch and going
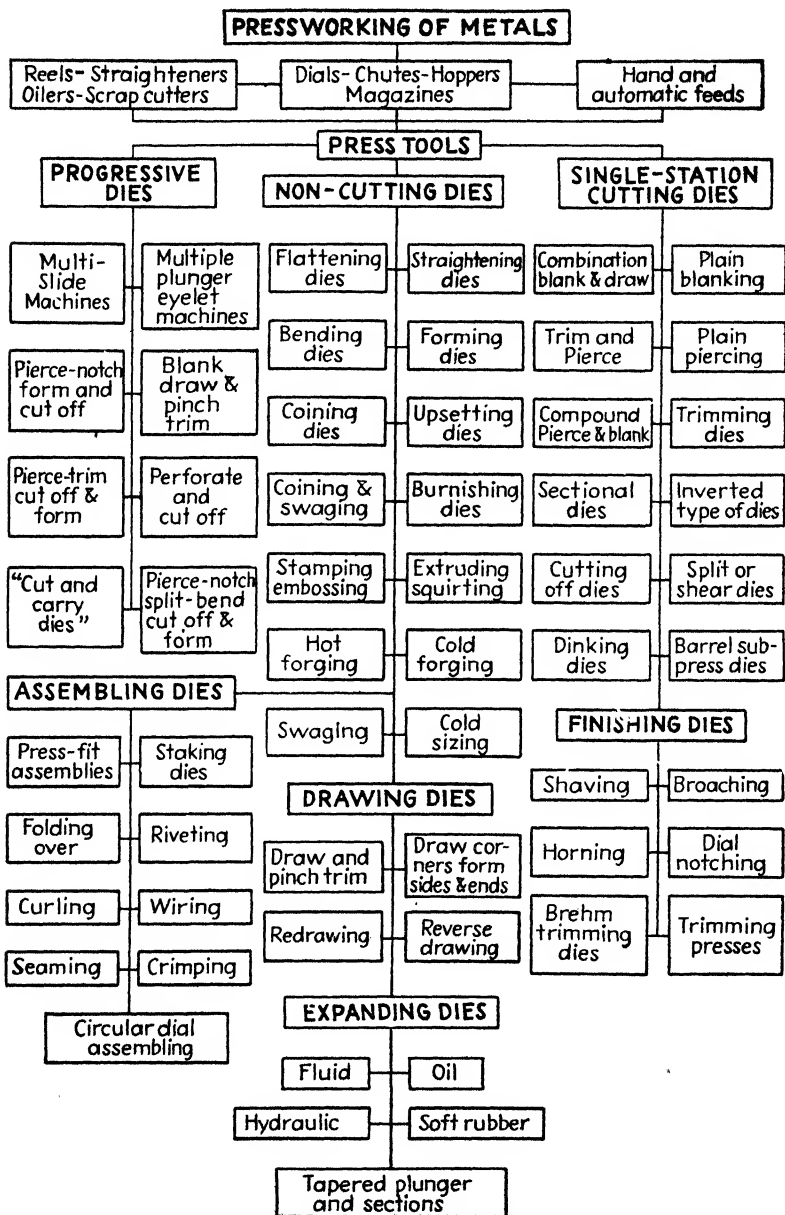
PRESSWORKING OF METALS

Reels-Straighteners Oilers-Scrap cutters	Dials-Chutes-Hoppers Magazines	Hand and automatic feeds

PRESS TOOLS

PROGRESSIVE DIES	**NON-CUTTING DIES**	**SINGLE-STATION CUTTING DIES**

Multi-Slide Machines	Multiple plunger eyelet machines	Flattening dies	Straightening dies	Combination blank & draw	Plain blanking
Pierce-notch form and cut off	Blank draw & pinch trim	Bending dies	Forming dies	Trim and Pierce	Plain piercing
Pierce-trim cut off & form	Perforate and cut off	Coining dies	Upsetting dies	Compound Pierce & blank	Trimming dies
"Cut and carry dies"	Pierce-notch split-bend cut off & form	Coining & swaging	Burnishing dies	Sectional dies	Inverted type of dies
		Stamping embossing	Extruding squirting	Cutting off dies	Split or shear dies
		Hot forging	Cold forging	Dinking dies	Barrel sub-press dies

ASSEMBLING DIES

		Swaging	Cold sizing	**FINISHING DIES**	
Press-fit assemblies	Staking dies				
Folding over	Riveting	**DRAWING DIES**		Shaving	Broaching
Curling	Wiring	Draw and pinch trim	Draw corners form sides & ends	Horning	Dial notching
Seaming	Crimping	Redrawing	Reverse drawing	Brehm trimming dies	Trimming presses

Circular dial assembling

EXPANDING DIES

Fluid	Oil
Hydraulic	Soft rubber

Tapered plunger and sections

FIG. 60.—This chart presents in classified order many of the names for press accessories and the dies used in pressworking of metals.

through the motions involved in the operation. Someone holds the stop watch and is ready to stop it instantly. When all is in readiness, the operator picks up an imaginary blank and goes through the motions of placing it in the die, pressing the clutch treadle, and removing the finished piece. These hypothetical operations should be repeated several times, and the average time noted. From these data, the labor cost per thousand pieces can be closely found for presswork.

Classification of Press Tools.—Figure 60 presents a nomographic chart in which most of the common types of press tools appear by name. Although it does not contain all the different press tools possible to make—there are an unlimited number of special dies—it does present to the die engineer a sufficient number of designs which are tied together in such a way as to suggest a solution for the many die problems likely to arise. The names and types of other dies are characterized by different shops, and this chart can be enlarged to suit individual cases.

Commercial Die Sets.—Die sets are made in many styles and sizes. The major parts are two members: a die shoe and a punch holder; these can also be purchased separately if desired and can be any reasonable specified thicknesses. More than standard thicknesses are often specified for inserting extra lengths of coiled springs in forming and drawing dies.

In assembled die sets, the punch holder is aligned over the die shoe by using two or more guide posts which are press fitted in the shoe and which slide through bushings in the punch holder. Guide posts may also be reversed; that is, they can be press fitted in the punch holder and slide through bushings in the die shoe, for purposes explained under Fig. 82.

For accuracy and strength, in high-precision die sets, the material for the punch and die holders can be of low-grade tool steel but left soft. The work clearance hole through the die shoe in blanking dies can be torch cut to the customer's sketch.

Guide-post lubrication is supplied by spiral grooves cut within the bushings, or annular grooves are cut in the bushings about ⅝ in. apart. The guide-post lengths should be ½ in. less than the shut tool height; this provides an oil pocket above the posts at all times. It is not good practice to specify the lengths of guide posts such that the ends of the posts are exposed when the die is open, unless this condition cannot be avoided. The better practice is to use extra long or shouldered bushings to prevent this condition. In some die sets, the lubricant is held within concentric holes drilled about 2½ in. deep in the upper end of the posts and from which small apertures lead the oil to the bushings.

Die-set illustrations, sizes, and specifications for all standard types can be procured from the supplier.

Tool Engineers' Scales.—Among several types of draftsmen's scales there should be two flat scales each 12 in. long. One scale is graduated in full inches by $\frac{1}{16}$- or $\frac{1}{32}$-in. divisions on one edge, and a half-size scale on the other edge with inch numbers at each half inch and graduated in $\frac{1}{16}$-in. divisions. The second scale is graduated in decimal tenths of an inch; it has full-size graduations on one edge and half-size graduations on the other. Black characters on white edges are easily read and do not cause eye strain.

Triangular metal scales with cut graduation lines are best for precision layouts. A sharp pencil point can be caused to glide down within the desired graduation line and dot the drawing for accurate distances. A very convenient scale is one where the zero line is placed midway on the edge of a 12-in. scale. From this point, the graduations read in inches toward the right and left. The zero line is placed on the center line of a drawing, and the dimensions can be rapidly laid out each side of the center without moving the scale.

The quality of drawing paper, tracing cloths, and vellums is a matter of individual choice. The use of green-tinted drawing paper is increasing; green rests and stimulates the sight and tends to prevent eyestrain.

CHAPTER X

AUTOMATIC STOPS

Manual or Automatic Stops Are Available in a Number of Designs for Application to the Dies or Can Be Built into the Machine

Hand Feed and Pin Stop.—This is the simplest method known for stopping a strip through the stations of a blanking die by hand. For feeding the strip from right to left, a positive stop pin (Fig. 61) is driven vertically into the face of the die block. The right edge of the pin is located from the right edge of the die contour, parallel with the direction of feed and by a distance equal to the length between blanking stations.

T = Thickness of material
B/c = Blanking centers between stations
W = Width of material strip
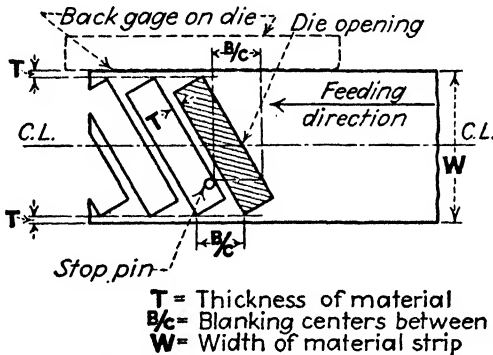
Fig. 61.—For hand feeding, the stop pin is placed well below the blank centerline for clearing over the pin when tilting up the front edge of the strip.

The height of the pin is about $1\frac{1}{2}$ times the stock thickness or more. The pin is placed well below the horizontal center line of the blanks to facilitate raising the front edge of the strip when passing the blanked hole over the top of the pin. Registering the right edge of the blanked hole against the pin exposes a new portion of the strip for cutting the next blank.

It is advisable to locate the pin from an angular right-hand slant in the die edge if possible, the same directional slant as the left side of the letter V. The reason for this is that when the cut edge in the hole registers against the side of the pin, the angular edge naturally forces the top edge of the strip against the back gage on the die.

Automatic Finger Stop.—The simplest design for this type of stop is given in Fig. 62. There are those who contend that this stop is no better or faster than a pin stop, but the usual reason behind the contention is that they do not fully understand how this particular stop should be designed. The slot in the stripper plate for the finger must be so loose, at point *A*, that the gaging end of the finger can move freely back and forth in a direction parallel with the feed of the strip. Width of the slot at this point should provide a clearance equal to the thickness of the material strip. The finger, although fairly tight at its fulcrum pin, should be able to touch both sides of the widened slot *A*.

A vertical trip pin from the punch holder contacts the pad and forces the feed finger up when the ram descends but not until after the blanking punch has entered the die. In this position, the tension
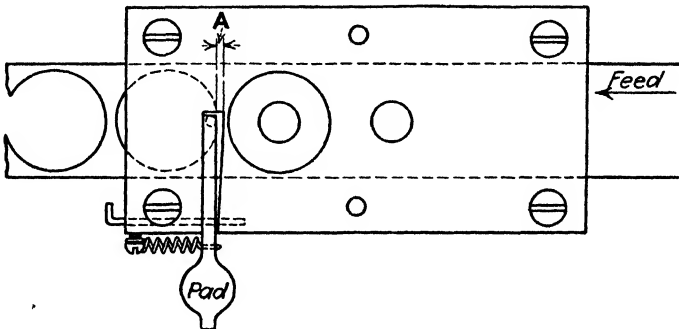
Fɪɢ. 62.—Automatic finger stops work properly only when the retaining slot *A* in the stripper plate provides a loose fit to permit a slight horizontal swing of the finger.

spring on the finger should cause it to hug the side of the slot nearest the die opening. Its successful operation depends upon the feed finger's coming down on top of the strip when the ram ascends and *not* in the blanked opening from which it was just lifted.

Commercial Automatic Stops.—These automatic stops are made in complete units and may be readily attached in any type of progressive blanking dies. They operate on a variation of the principle already described, with the position of the stop being changed. The finger of these stops is revolved 90 deg. toward the left on point *A*, from the position shown in Fig. 62. The finger is thus parallel with the material strip, and the pad extends over the left end of the stripper plate. A vertical trip pin from the punch holder contacts the pad and forces the finger up, when the ram descends.

There is no looseness in the slot that confines the finger. The "flip-over movement" which causes the stop to land down on the strip, when the ram ascends, is accomplished by a vertical stop pin loosely

attached to the end of the finger by a ball joint. The ball that carries the stop pin is really a separate pin which slides in a hole drilled in the end of the finger parallel with its length. A compression coil spring behind this pin acts for the same purpose as the tension spring in Fig. 62. This mechanism is held together by confinement within a combination slot and hole through the stripper plate.

Automatic Finger Stop Attached in the Press.—This equipment is fully adjustable. It can be purchased separately and attached in the press, as shown in Fig. 63. It is designed for use on open dies that have no attached stripper plate in which to operate the conventional automatic stop. By its use, the press can be run continuously.

Automatic Stop at Rear of Die. A finger feed is also used to operate a side-swing automatic stop. In this case the finger is pinned on a horizontal shaft mounted, right to left, on top of the stripper plate, in the rear of the die. Necessary looseness, required to allow the finger to pass the top of the strip before registering, is accomplished by a proper clearance fit of the finger on the shaft. The further side of the finger from the die positively stops against a pin driven in the top face of the stripper plate, and a wire spring forces it to clear over the neck in the strip before descending into the next blanked opening.

Fig. 63.—An automatic finger stop can be attached in the press frame for dies having no stripper plate in which to operate the conventional finger stop.

Automatic Stop for Roll Feeds.—A finger motion used in connection with roll feeds consists of a cross shaft carrying a finger that acts as a stop when down. This stop, shown in Fig. 64, is raised and lowered between feeding intervals by means of a tripping arrangement operated from the ram, in connection with a spring.

Vertical-pin Automatic Stop.—Figure 65 illustrates the idea. The right side of spring pin A is the stop. The pin is located to suit the blanking centers of the die. The face of pin B is adjusted a suitable distance ahead of the blanking punch face; it is then locked by tightening the nut shown on the hook bolt. Pin B is $\frac{1}{32}$ in. *less* in diameter than pin A and is located so that the $\frac{1}{32}$ in. is distance C. When the
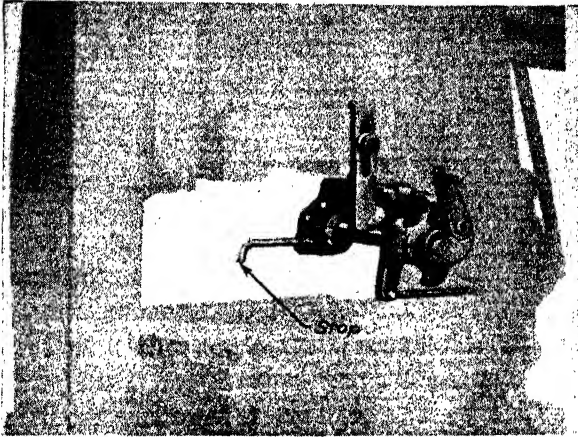
FIG. 64.—This finger stop is attached to the ram. It is raised and lowered, between feeding intervals, by the movement of the ram and a coiled spring connection.
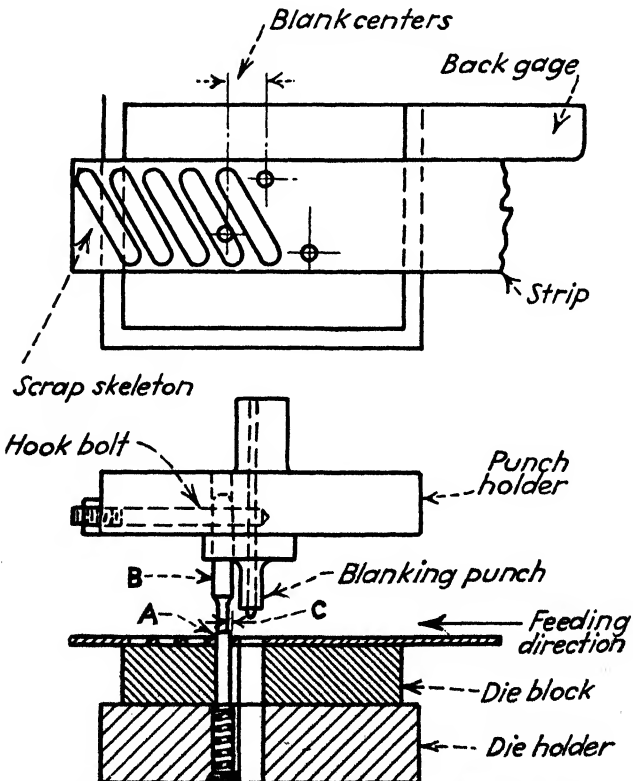
FIG. 65.—A vertical pin automatic stop, in which dimension *C* permits the blanked strip to ride over and stop against pin *A*, when the ram ascends.

ram descends, the face of pin B contacts and depresses A. Before the surface of A disappears below the underside of the strip, the blanking punch begins to cut. The ram, continuing in descent, depresses A below the surface of the die block.

In ascent, the strip is carried up with the blanking punch as usual. When the top surface of the strip comes in contact under the stripper-plate channel (stripper plate omitted for clarity), the punch withdraws, and the hand pressure on the strip causes the bridge to come in contact with the right side of pin B. As ascent continues, pin A follows up but contacts the strip under the bridge between the blanked holes, while pin B ascends out of the stripper plate. With B removed, the advance of the strip exposes the blanked hole over A and allows it to attain instantly its normal free height. The right edge of the last blanked hole then registers firmly against the side of A. This action completes the cycle, and the strip now presents a new surface for the next blank.

This stop is used for blanking rather heavy material where the width of the scrap bridge is $\frac{3}{32}$ in. or more. Its fault appears when attempting to blank thin strips having narrow bridges or when the location of A leaves insufficient steel between the edge of its hole and the left edge of the die opening.

Self-contained Automatic Stop.—A unit automatic stop that can be stocked in quantity for future use is illustrated in Fig. 66. Body
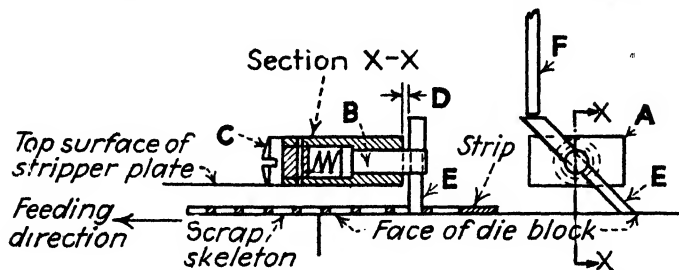
Fig. 66.—In this self-contained automatic stop, the stop pin E is rotated away from the gaging edge by the descent of the vertical pin F; it is then forced over the scrap bridge by the action of a coiled compression spring.

A is a cold-rolled steel block counterbored for plunger B which is a working fit. Cap C closes the spring chamber. The cap is provided with a screw-driver slot and pinned through, for adjusting the torsion of the attached spring within the chamber. The coiled spring acts both in compression and in torsion. In compression, it maintains dimension D open until the strip is pushed forward and closes it for cutting the next blank. Dimension D is equal to the thickness of the work material.

The ram, in descent, carries down the vertically adjusted trip pin F which is attached in the punch holder; the pin makes contact with E and rotates it away from the blanked edge where it has been engaged. This occurs after the punch has entered the die. In this position, the spring forces B and E forward so that when the ram ascends and carries away the trip finger, the torsional action of the spring causes B to rotate E down upon the scrap bridge. The strip feed then advances the right edge of the last blanked hole firmly against the side of E which completes the cycle.

Automatic Stop for Continuous Feeding.—Figure 67 shows a straight-punch automatic stop which enters the die considerably ahead of the blanking punch. This type can be used only where the strip is being continuously fed forward by rolls or other means. It is used mostly for high-speed blanking.
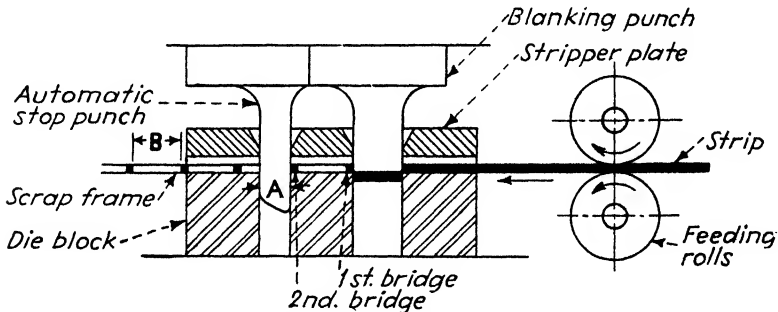
Fig. 67.—A straight automatic stop punch enters a blanked hole in the strip, and registers it for cutting the next blank. This type of stop is used in cases where the coil strip is passed steadily over the dies by a pair of automatic feeding rolls.

The stop is placed two stations ahead of the blanking operation, as shown. If the length of the stop is too long, it will enter the die before the second bridge has been sufficiently advanced and then "jam." If its length is too short, it will fail to enter the die soon enough and jam the first bridge, instead of stopping against it as desired. Obviously, if the length of the stop lies between these two extremes, it will enter the die at the right time and stop the strip correctly. Width A of the stop should not be greater than half the width of B, which is the blanked opening.

Notching the Strip for an Automatic Stop.—In Fig. 68 notch A is cut in the strip edge by the descent of punch B and at a distance from the stop toe on C equal to the blanking centers. The first position of the strip is as shown, with its forward end stopped against the toe. When the ram descends, the stop is withdrawn by the sliding action of the angular face on plunger D, which causes the stop toe to ride

against the edge of the strip, because of clearance angle E and the pull

FIG. 68.—A notch cut in the strip is advanced ahead one station into a stop toe, the toe is automatically withdrawn in time to allow feeding to proceed.

of tension spring F. As the ram ascends, the punches are stripped, and D withdraws. The material can now be advanced until the stop toe engages in slot A in the strip. The first station on the strip is now exposed under the punches for piercing and blanking. The work is then ready to be passed rapidly through the die with the press "running open" and with a constant feeding pressure on the strip. Plunger D can be easily adjusted longer or shorter.

Automatic Stop That Sizes the Strip Width.—An unusual automatic stop for light-gage material is illustrated in Fig. 69. The die openings are shown section lined. Punch A, provided with a backing-up heel, enters the die and cuts a notch in the edge of the strip simultaneously with blanking. The notched length is equal to the blanking centers of the die. The strip is then advanced for cutting the next blank, and the previously cut notch registers against the

FIG. 69.—Automatic stopping is secured with negligent waste by notching the strip edge with punch A, the length of notch being the blanking center distance.

stop. Punch A has a small projection at point B. The purpose is

to cut across the corner in the notch and thus prevent leaving a fin. The notch is cut a suitable distance into the edge of the strip, which may be about $\frac{1}{16}$ in. for most light-gage stock.

Both the stop and the notching punch are shown at the rear of the die, but they could be used at the front edge of the strip. In "cut-and-carry" types of dies, in which the blank is cut to shape on the surface of the die, this stop can be used to advantage. The notching punch determines an accurate width of strip at C. In cut-and-carry dies, this feature is often important. The piece sheared from the strip is waste; but for light strips of low-cost materials, the advantages gained in die performance may offset the loss.

Pawl-type Automatic Stop.—A cheap and efficient stop for blanking strip stock is given in Fig. 70. This stop is easy to install and
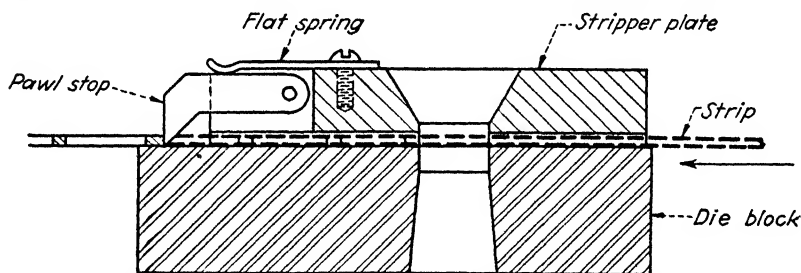
Fig. 70.—A cheap and effective semiautomatic pawl stop, easy to install in any blanking die.

seldom needs attention or repair. It is operated by the movement of the strip and is entirely independent of the punch movement. As implied by its name, it is simply a horizontal pawl secured on a fulcrum pin fixed in the stripper plate. Side clearance, needed in other stops to cause them to swing over on the strip, is unnecessary.

The pawl lifts up against a flat spring, when the strip is fed under it, and its point drops into the next blanked opening. The operator then pulls the strip back slightly, until the left edge in the blanked opening registers against the point on the pawl. Press operators soon become familiar with this rhythmic motion, and over 40,000 pieces of average-sized blanks can be produced daily. Some press operators prefer using this stop rather than a swing stop. The pawl point is located outside the left edge of the stripper plate, in plain view and in convenient position for change or repair. Grinding or peening the point face will alter the blanking lengths when necessary.

CHAPTER XI

BLANKING AND CUTTING DIES

Punch and Die Clearances Are Often So Intermingled that the Designer Must Proceed Carefully in Order to Produce Correct Sizes of Blanks and Holes. Principles of Construction for Plain and Compound Dies

Blanking Punch Clearance.—Consider the relation between cutting edges of the blanking punch and die shown in Fig. 71. The contour edge of the punch is separated by the exaggerated space C from the contour within the die opening. Space C is the punch clearance on one side. Side clearance is one-half the over-all clearance. In a die for circular blanks, for example, the over-all clearance is the difference between the punch and die diameters. Punch clearance is uniform in width and extends all around between the punch and the die.

The necessity for punch clearance is threefold. It reduces the press exertion necessary for blanking and promotes smooth shearing action. It prevents actual contact between the cutting edges of the punch and die which avoids nicking or breaking them. The ideal clearance produces a blank free of burrs and with fairly smooth edges.
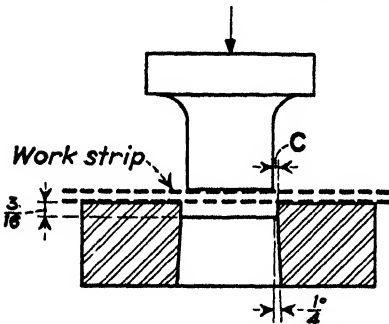
FIG. 71.—Smooth cutting and shearing actions of the punch and die are determined by several variables: punch clearance, sharp cutting edges, and physical properties of the material. Here is shown the side punch clearance at C.

If punch clearance is too small, the usual shearing fractures that extend through the work thickness, between the edges of the punch and die, fail to meet as they should but pass when shearing through, and a rough-edged blank is the result. If punch clearance is too great, then the tool begins to operate like a drawing die. The work may even resemble a drawing job. There will be large round corners on the die side of the blank and a heavy burr around the punch. The finished blank appears like a shallow receptacle having thinly drawn sides. A drawing die, in principle, is similar to a blanking die in which the side

clearance is equal to the blank thickness and which has suitable drawing radii in place of sharp cutting edges.

The ideal punch clearance depends upon the area and thickness of the blank, its physical properties and resistance to shear. New high-speed presses show that a high production of blanks per minute may, in some instances, require more than usual punch clearances.

The general rule for over-all punch clearance is based on a percentage of the blank thickness. It is 5 per cent of the thickness for brass and soft steel, 6 per cent for medium hard-rolled steel, and 7 per cent for hard-rolled steel. If T represents the blank thickness, punch clearances are then $T/20$, $T/16$, and $T/14$. These constants are practically the same as using 5, 6, and 7 per cent, respectively.

In blanks where a rough edge, out of square, is not objectionable, more than the usual punch clearance is allowed to ease press exertion. A blank die for an automobile bumper guard of $\frac{1}{8}$-in. drawing steel may have a side clearance of $\frac{1}{64}$ in., or $\frac{1}{32}$ in. over all. Sheet aluminum, over $\frac{1}{8}$ in. thick, requires more clearance than does brass. It runs from 8 to 14 per cent for $\frac{1}{8}$ to $\frac{1}{2}$ in. thicknesses.

Blanking Die Clearance.—The $\frac{1}{4}$-deg. angle shown in Fig. 71 is the die clearance. Die clearance is uniform all around within the die opening. Its object is to clear the edges of blanks as the punch, in descent, pushes them through the die. Dies are usually filed straight about $\frac{3}{16}$ in. deep from the top surface before die clearance begins. When die clearance begins at the die surface, it has the fault of increasing punch clearance and blank sizes each time the surface of the die is reground for sharpening. This increase is, however, very small. In a die having $\frac{1}{4}$-deg. clearance, one grinding that reduces the die thickness 0.005 in. increases the over-all blank size only 0.00004 in. But even this small increase becomes 0.004 in. when $\frac{1}{2}$ in. has been ground off.

The clearance angle may be more or less than $\frac{1}{4}$ deg., depending on the nature of the work material; its hardness, thickness, and blank area; and whether or not an increase in the blank size, after grinding the die, is objectionable. Compound blanking dies have no die clearance. It is unnecessary in dies of this kind where the blank is ejected immediately after cutting, instead of being pushed through the die.

Penetration and Shear.—Analysis of the cutting action between the punch and die (Fig. 71) shows two conditions that invariably occur in shearing through a blank. First, the punch, in descent, must sink into the strip sufficiently deep to overcome the shearing resistance of the material (Fig. 72). Second, continuing in descent, the punch

breaks the blank through, with more or less loud report, and then pushes the blank into the die (Fig. 73).

The first condition, sinking, is called "penetration"; the second condition, "the break"; combined they are known as "shear." The pressure exerted on the blank by punch penetration naturally produces a bulge or round-edged corner under the blank and within the edge of the die (Fig. 72). It is sometimes necessary that this rounded edge, or the "die side of the blank," be on a specified surface of the blank, and the die is therefore designed accordingly. In practice, however, a small percentage of the sinking process occurs around the die edges; there is a trace of sinking noticeable around the die edges of very hard metal blanks and in dies having insufficient punch clearance.
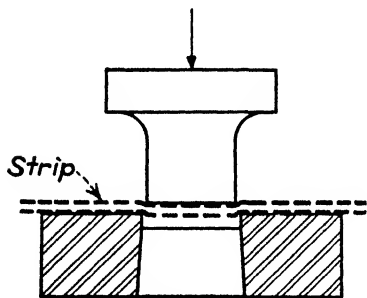
FIG. 72.—Punch penetration sufficient to overcome the shearing strength of the material.
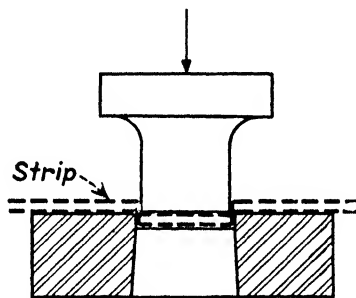
FIG. 73.—"Breaking through" the blank into the die.

The foregoing shearing conditions refer to punches and dies having flat faces and sharp edges. With dulled cutting edges, press exertion is increased, burrs are produced around the punch, and increased rounded edges appear on the die side of the blank. The metal, under penetration pressure, "flows" under the worn edge of the punch and up around the sides of the punch and forms a sharp ridge, or burr. This condition is sometimes taken advantage of when needing such blanks.

Determining Shearing Faces on Punches and Dies.—In large cutting-off and blanking dies for heavy materials, the cutting members are provided with angular shearing faces. This reduces the required shearing pressures by one-quarter for metals over $\frac{1}{4}$ in. thick and by one-third for lesser thicknesses. A die should not be used in a press if there is any danger of the press exertion fracturing either the crankshaft or press frame.

The height of the shearing angle should not exceed the blank thickness (Fig. 74); otherwise the blank may be distorted. In fact, by using

either a concave or a convex shear on the punch face, blanks so shaped can be produced. For cutting ordinary blanks, "shear" is usually ground on the die face; but for piercing large holes or cutting openings within the blank, the punch carries the shearing face.

There are instances in blanking, however, when a shearing angle on the die face is inconvenient. The shape of the blank, or its position in the tool, and facility in passing through the strip are conditions that often favor making the punch carry the shear. These conditions are more than likely to arise in the design of large blanking dies with long cuts through thick material.

Determining the Blank and Hole Sizes.—It is evident in Fig. 72 that in the operation of blanking, two important conditions are present relative to sizing. First, punch penetration determines the size of the
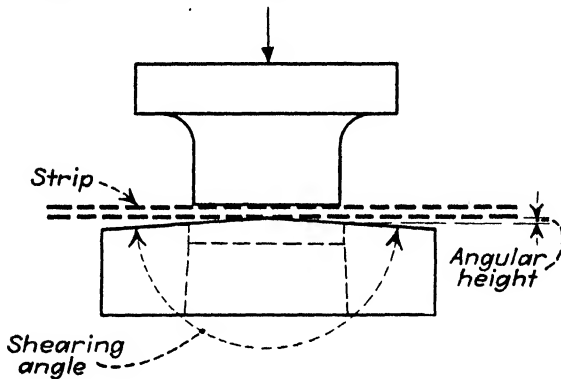
Fig. 74.—Power required by large blanking and cutting-off dies is reduced materially by the use of angular shearing faces on either the punch or die. In blanking dies, shear is ground on the die face.

opening cut through the strip. Second, the die opening determines the cut size of the blank. Therefore, punch clearance is added to the die opening for piercing but is subtracted from the punch for blanking. In other words: *The punch governs the size of the hole, and the die governs the size of the blank.* These are important conditions, because they actually determine the cutting dimensions for the punch and die members. For very accurate piercing, the over-all size of the punch is made 0.002 in. larger than the size desired because pierced holes close in 0.002 in. after being stripped from the punch. Piercing punches for materials $\frac{3}{32}$ in. thick and up usually have a slight side relief of about $\frac{1}{16}$-in. taper per foot. Side clearance on the punch facilitates stripping, but it is generally used on punch diameters of $\frac{1}{8}$ in. or more. Punches that must be guided through the stripper plate in bushings have no side clearance.

Computing the Punch Clearance.—For accurately piercing and blanking a washer of hard-rolled steel $\frac{1}{16}$ in. thick and 1 in. outside diameter, with a $\frac{1}{2}$-in. diameter hole: the over-all punch clearance is 7 per cent of the stock thickness, or $0.07 \times 0.063 = 0.0044$ in. The blanking die opening is therefore 1.000 in. diameter; its punch is 0.9956 in. diameter; whereas the piercing punch is 0.502 in. diameter, and its die opening is 0.5064 in. diameter.
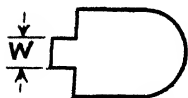
FIG. 75.—Since the punch governs the cut size of width W, the punch really functions at this point as a die, and the width between the cutting edges of the punch should be the same as W. Punch clearance is subtracted from the tongue in the die.

Blank sizes are sometimes governed by the punch. This condition may occur when the punch has opposite cutting edges on both sides of an arm or protrusion from a blank, as shown across the width W in Fig. 75, in which the punch governs the cut size of W. In all such cases, the punch really functions as a die *locally* across the projection W. The width between cutting edges in the punch should be the same as W, and the punch clearance is subtracted from the supporting tongue or projection in the die. This calls attention to the fact that in some cutting dies, the punch and die functions are so intermingled that the designer must employ careful thought in order to analyze correctly.

CONSTRUCTION PRINCIPLES OF PLAIN AND COMPOUND DIES

Using "Push-off Pins."—A blank may be too thin or too regular in outline to "cling," as it must, in the die opening after blanking. This difficulty often occurs when using a lubricant on the strip. Excessive oil causes the piece to adhere to the punch and follow it up in ascent. Faulty diemaking also causes this trouble. If the die opening is filed incorrectly—slightly flared outward toward the top instead of having vertical sides—the die may fail to retain the blanks.

· Safe tool engineering specifies one or more push-off pins in all blanking punches for small thin blanks of regular contours. The pins are $\frac{1}{16}$ to $\frac{3}{16}$ in. in diameter, or to suit the blank size, and slide through the punch as shown in Fig. 76. The pins normally protrude beyond the punch face about $\frac{1}{4}$ in. A light compression spring is placed over the head of the pin in the punch holder. These push-off pins hold the blanks down within the die while the punch ascends.

Push-off pins are sometimes inserted through the die block with the compression spring placed under it in the shoe. The idea is to lift the work slightly and thus facilitate the strip movement, or to elevate the strip and clear a formed part on the blank over a die edge. This necessity often arises in the design of progressive dies where the blank

outline is cut with notching punches from either side of the strip and, being attached to the strip, is advanced into subsequent stations for additional operations. The ends of the pins have rounded noses, and the strip slides over them easily; the pins project above the die face about $\frac{3}{64}$ in.

Inverted Dies.—Sometimes it is found necessary in press tools to reverse the positions of the cutting members in the die set. The punch then becomes the lower member and is attached to the die shoe, while the die is mounted over it on a punch holder. A spring pad, retained by stripper screws in the die shoe, surrounds the punch. The surface of the pad is normally flush with the punch face. It guides the material strip over the punch and at the same time locates the strip edgewise between the slotted guides shown in Fig. 77. When the ram descends, the die depresses the pad an amount equal to the distance the punch enters the die,
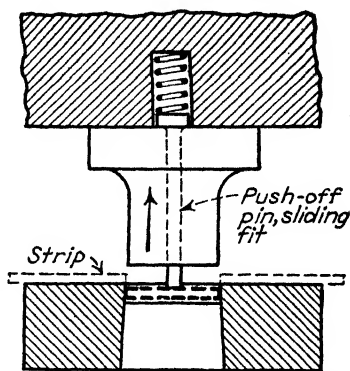
Fig. 76.—Small, thin oily blanks of regular contours sometimes adhere to the punch face in ascent; to avoid this trouble, a spring push-off pin is made to slide through the punch; it holds down the blank in the die while the punch ascends.
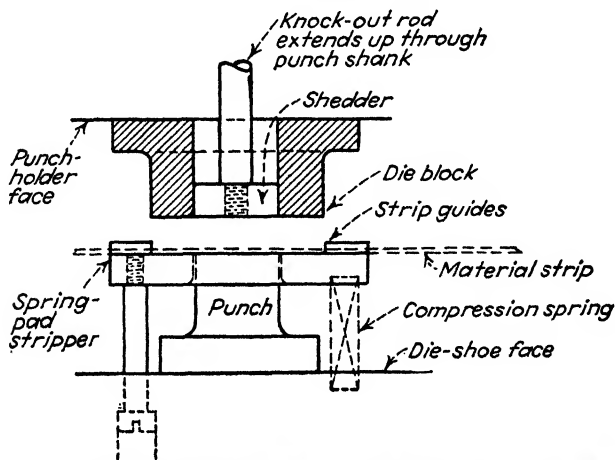
Fig. 77.—Inverted blanking dies can be used on presses wherein the press-bed opening is too small for the blank to drop through.

plus the thickness of the work material. The blank has now been cut into the die, and the material strip has been cut through and clings around the punch. When the die ascends, the spring pad

follows it and carries up the strip from around the punch, or "strips it off the punch," as a diemaker would say.

After the blank has been cut into the die, it is carried up within the die and ejected by a "knockout" shedder which has an attached vertical rod, as shown. The shedder is a free fit within the die opening. Blank ejection occurs near the top of the ram ascent, at the moment when the free end of the knockout rod contacts the ejector bar which extends through the head of the press. The sudden contact depresses the shedder, which lies behind the blank, and instantly pushes the piece out of the die. Press tools of this type are usually "set up" on an inclined press; the ejected pieces slide off the die and then fall into a chute which conveys them into a container behind the press.
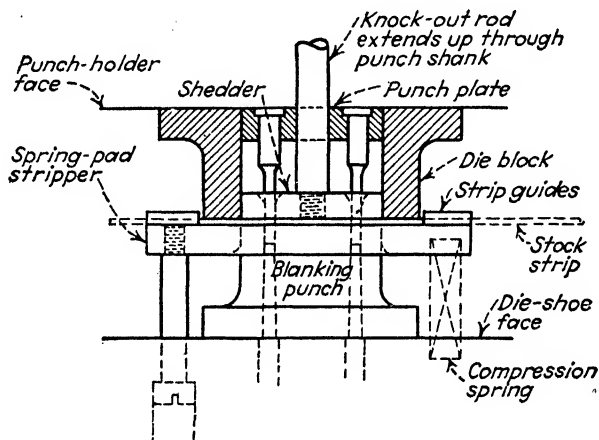
FIG. 78.—A compound, inverted blanking die has the advantage of locating pierced holes in accurate relationship to the blank contour.

Inverted dies are used mostly for drawing. Blanks ejected from vertical dies interfere on the strip. A method to avoid this trouble is discussed under Fig. 344.

There are several advantages in using inverted dies. This tool is quite unlike the conventional die in which the blanks pass through the die and bolster and then fall beneath the press. Inverted dies have the advantage of using a solid bolster and a minimum size of opening through the press bed. It is therefore possible to use a press that has an opening in the bed too small for the blanks to drop through, which would be impossible using a conventional blanking die. The solid die shoe and bolster plate and the minimum-size press opening under them provide maximum resistance against the thrust of heavy cuts and a noticeable absence of press vibration, or "spring," during the cutting interval.

Principles of Compound Dies.—There are further advantages in using inverted blanking dies. If holes or openings are to be cut in the blank, the necessary punches can be located within the die and be extended through holes in the shedder plate (Fig. 78). Corresponding die holes for the cuts are provided in the face of the blanking punch. Thus we have a simple type of compound die in which the locations of all the pierced holes are in accurate relation to the contour of the blank. Accuracy is due to cutting the blank and holes in one station simultaneously, but the tool must be true.

Occasionally, one is confronted with a die-designing problem that is solved best by using an inverted die. This condition often appears at certain stations of progressive dies when shearing, forming, embossing, or drawing one or more parts of the blank, up or down from the surface of the material strip. In such cases, one finds that an inverted die will sometimes avoid interferences in passing along the strip. There are also times when both the conventional die and the inverted types are combined in one station or at different stations in progressive work. Therefore, when the designer seems to be "stumped" in procedure, turning the drawing upside down may give him the desired clue which suggests that an inverted, or compound, design is best.

MISCELLANEOUS DETAILS FOR PIERCING AND BLANKING DIES

Disposing of Slugs and Blanks in Large Dies.—In very large piercing dies, where perforated holes are widely scattered and some are
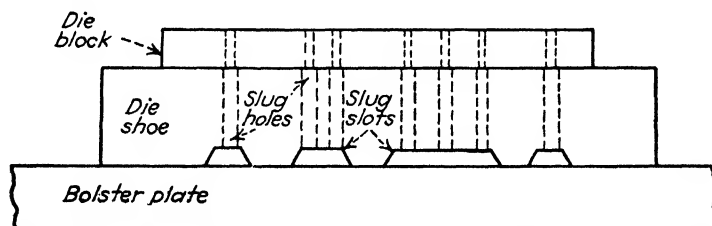
FIG. 79.—When perforated holes are so widely scattered that some of the slugs will not fall through the press-bed opening, cross slots are machined in the underside of the die shoe, and the slugs can be pushed out occasionally.

too far removed for the slugs to fall through the opening in the bed of the press, the die-shoe casting is made with a series of parallel cross slots underneath it. The slots are positioned under the holes that lead from the die. After piercing, the slugs fall through into these slots and lie on the bolster plate; they are pushed, or blown out with an air nozzle (Fig. 79).

Using cross slots underneath the die shoe, as just described for the disposal of pierced slugs, is an idea well adapted for disposing of blanks

that are too large for passing through the opening in the press bed (Fig. 80). After being cut, the blanks fall into the die-shoe channel and are then easily pushed out.

The sketch also shows "stop sleeves" around the guide posts. This feature aids the die setter in adjusting the ram to its shut height; it also checks the lost motion in a worn ram slide. The tool-steel punch sections are "backed" with a cold-rolled steel block, as shown; this is economical in the use of tool steel.

Composite steel blocks are sometimes used for punch-and-die sections; such blocks are of machinery steel having a "welded-on" tool-steel face. They are called "steel-clad blocks." In large dies, the
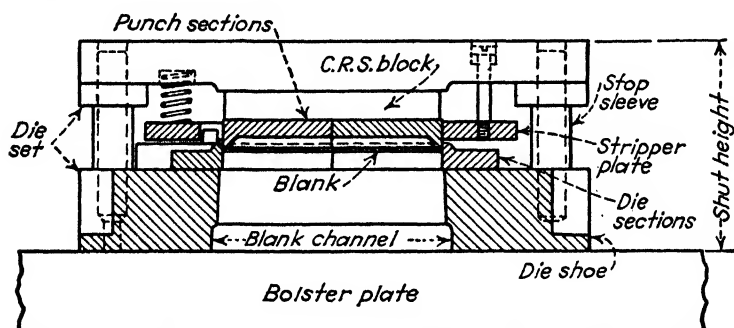
Fig. 80.—Large blanks that will not pass through the press-bed opening can be pushed from a channel underneath the die shoe.

punch holder is usually secured to the ram with bolts; hence the punch shank is omitted in the figure.

Tapered Outlet Holes Prevent Pierced Slugs from Jamming.— Figure 81 shows how the tapered clearance hole *A*, leading from a piercing die, is continued through the die holder to prevent the pierced slugs from crowding together and clogging. If this is not done, small slugs will interlock and jam across the diameter of the outlet hole. Slugs often jam so tightly that it is necessary to remove the die from the press and drill them out.

Inverted Guide Posts in Die Sets.—It is evident, as shown by the reversed guide posts in Fig. 82, that when the guide-post bushings are placed a greater distance ahead of the press slide than in the conventional die set, there will be better guiding of the punch straight into the die. This principle is often used to advantage in dies where thin materials are pierced and blanked and where there are necessarily little or no punch clearances.

The method of construction is to press fit the guide posts into the punch holder; and with the guide bushings fitted in the die shoe,

practically all the looseness in the press slide is eliminated while operating the die set. Tubular safety guards are placed around the guide
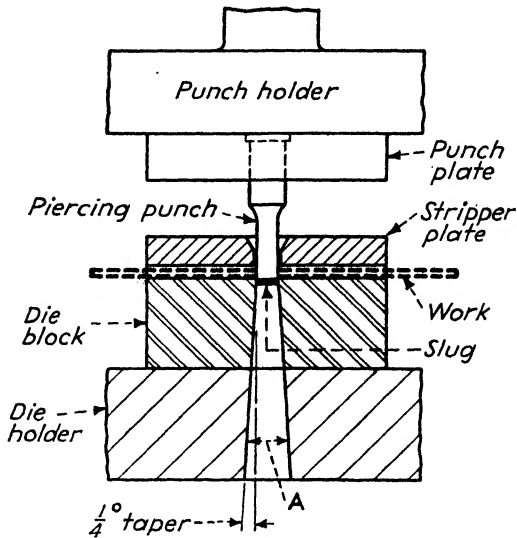
FIG. 81.—When the clearance hole through a die block is tapered to clear pierced slugs, if the taper is continued through the die holder, clogging of slugs in the clearance hole is eliminated.
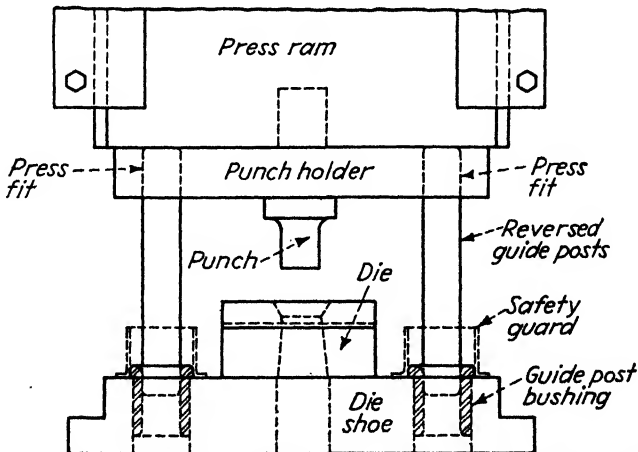
FIG. 82.—If guide posts and bushings are reversed from the positions used in conventional die sets, the inaccuracies of a worn press slide are practically eliminated in the die set, when the punch holder is in motion.

posts and secured on the die shoe. The guards protect the operator from accident if he should inadvertently place his fingers under the end of a guide post that lifts above the bushings before descending. The

advantages in using reversed guide posts have been proved by diagrams that show the lines of reactions and triangular forces for both systems, but this is a discussion too long for presentation here.

Making Die-cutting Members of End-grain Steel.—In very accurate dies in which thin stock is to be cut, it is advisable to order the steel so that all the cutting members can be finished with the steel grain vertical. This condition is true, of course, in the case of piercing punches made from round stock, and the same idea can be incorporated in the blanking and shearing members. The advantage of this feature is said to be that the cutting edges are less likely to chip off when punch clearances are very small and the edges come into contact.
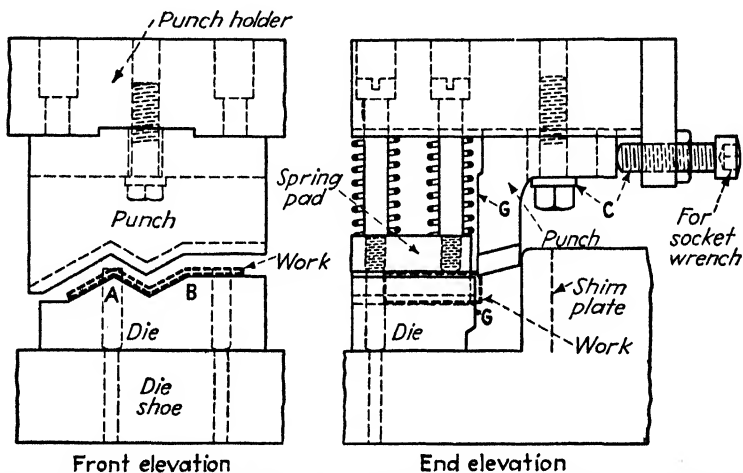
FIG. 83.—Work pieces of irregular shapes can be cut or trimmed by employing die designs of this type.

Cutting Off Pieces of Irregular Shapes.—Figure 83 shows the general principle employed for trimming or cutting off work having irregular cross sections. It is best in such cases to arrange the position of the work in the die so that two of its heights A and B are in the same plane. For sharpening, both the punch and die are ground on their vertical faces, as indicated by G. Grinding the die reduces its width, and the points of work registry on the stop pins must likewise be reduced so that the sheared width of the work will not be changed. The punch is then moved forward into cutting position and secured by screws C.

Small Punches near a Larger Punch Must Be Made Shorter.—Figure 84 shows a slender piercing punch located close to a blanking-punch edge. It is advisable to make the length of the pierce punch

less than the length of the blank punch, by an amount equal to the material thickness T. This precaution avoids deflection of the smaller punch when the larger punch "sets up" a plastic deformation of the metal when starting to cut.

Both the pilot and the piercing punch are held by square-shouldered heads. This design prevents the piercing punch from pulling out of
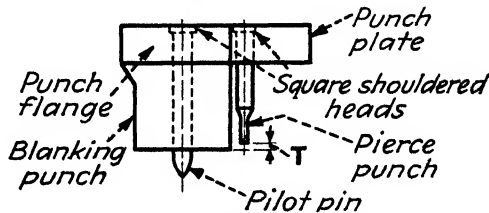
FIG. 84.—Slender piercing punches are made shorter than a nearby blanking punch by the thickness of material T, to avoid deflection when the larger punch crowds the metal.

the punch plate when stripping. This type of small punch head is better than the common practice of riveting over the head into a countersunk hole as seen in Fig. 85.

When there are two or more piercing punches close together, as in Fig. 85, it is good practice to "step" the lengths of the punches as shown. The difference between the lengths of the punches should be sufficient to prevent the crowding of metal between them when cutting.
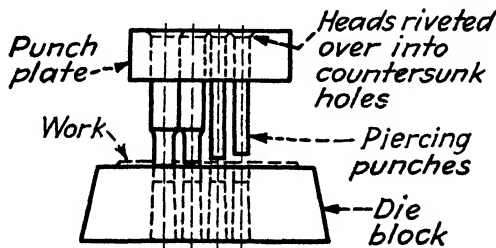
FIG. 85.—Deflection of close together piercing punches is caused by crowding of metal between holes; it is avoided by making the punches of stepped lengths.

In multiple piercing of holes, as in shaker tops, colanders, and similar kitchen utensils, close-together punches of equal lengths will crowd together and cause serious cutting deflections. The remedy is to vary the lengths of punches.

Raising Protruded Slugs.—When the punch in Fig. 86 ascends, the spring shedder follows up the punch and ejects the work from the die. Meanwhile, the positive plate, shown above the work, strips it from the punch. Diameter of the protrusions will be between 0.001

and 0.002 in. larger than the die openings. This increase should be considered for precision work.

Portable Perforating Punches.—Commercial drop-forged steel screw punches are available in several sizes for punching holes from $\frac{1}{8}$ up to 1 in. in diameter. An illustration of the design is represented by Fig. 87. One of the larger screw punches weighs 180 lb., and dimension A is $6\frac{1}{2}$ in. and B is $4\frac{1}{2}$ in. These tools are operated by using a steel bar through the holes in the screw head or by applying a wrench on the square head. Perforations 1 in. in diameter are pierced without difficulty through boiler plates $\frac{5}{8}$ in. thick. There are smaller screw punches that weigh only 5 lb. for piercing a maximum sized hole of $\frac{3}{8}$ in. diameter through $\frac{1}{8}$-in. sheet steel.
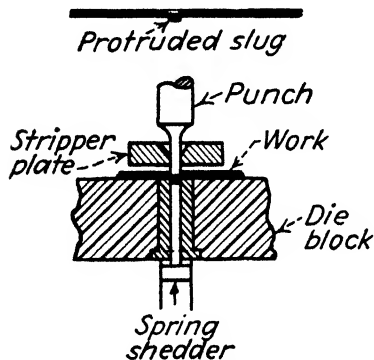
FIG. 86.—Die for raising a protruded slug. These slugs enter corresponding holes in other parts and insure an accurate assembly.
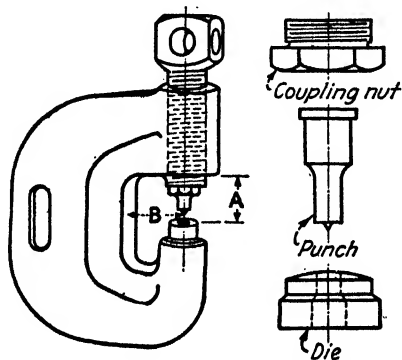
FIG. 87.—Commercial screw punches are built to perforate holes up to 1 in. in $\frac{5}{8}$-in. boiler plate, and can be fitted with various sizes of punches and dies.

A large variety of sizes in punches and dies can be cheaply purchased for these tools. A center-point projection is provided on the punch faces. The point on the punch is first located in a center-punch mark made in the sheet where the hole is wanted, and then the punch is forced through the material by the screw.

These tools are convenient for perforating holes through plates that are attached on a machine or for plates too cumbersome to drill or to be carried to a punch press for the operation. With this tool, the punch and die can be taken to the job.

A recent improvement in this tool, which greatly increases its speed, is the attachment of a cylinder and piston in place of the screw for operating the punch. The punch is then reciprocated either hydraulically or pneumatically. Although the improved tool is more expensive, nevertheless it is of great value in the final assemblies of

considerable quantities of work, such as streamlined coaches, tanks, tractors, and airplanes.   Not only does it pierce the holes in light materials, but by substituting riveting members in place of the punch and die it can be used for squeezing and heading hot and cold rivets.

Adjustable Piercing Die.—A press tool that saves much time and is very inexpensive to make is a universal piercing punch and die, similar in principle to the one shown in Fig. 88.   This tool is useful when building apparatus from standard structural-steel sections.

Stripper yoke *A* is made from $\frac{1}{2}$-in. strip steel.   The elongated slots are for capscrews that secure the yoke to the press head.   These slots also provide for vertical adjustment of the stripper face for different thicknesses of work. The punch holder carries the sliding quill *B*, the lower end of which is tapped to receive the com-

Fig. 88.—A formed stripper yoke fastened to the head of a deep-throat press and with sliding quill *B* attached to the punch holder, can be used with a commercial coupling nut and punches and dies for piercing holes anywhere in a wide sheet.

mercial coupling nut and punches shown in Fig. 87.   The die block is provided with commercial dies.

For piercing any number or diameters of holes in duplicate sheet-metal parts, and in any quantities, a center-punching templet is made with $\frac{3}{16}$-in. holes located to suit the parts to be pierced.   The templet, of $\frac{1}{8}$-in. sheet steel, is fastened over the work piece similarly to a plate-drilling jig.   A $\frac{3}{16}$-in. center punch is used through the holes in the templet to mark the hole centers.   The templet is then removed, the work is placed on the die, and the sliding quill is raised to admit placing the punch point into the centering mark.   The press is then operated, and the hole is pierced.

A method for reducing the vertical descent of a punch to a distance *less* than the press stroke *S* is also shown in Fig. 88.   The punch in the sketch really descends only a distance of *S minus C*.   If the press stroke is $1\frac{1}{2}$ in., and *C* is $\frac{1}{2}$ in., the punch descends only 1 in.

All the standard sizes of punches and dies can be purchased for this tool at a fraction of the cost for making them.   This die has no guide posts.   These would interfere with the work when punching holes far within large sheets.   Without guide posts, the rear limit of the work-sheet size is the throat depth of the press.

Universal Notching Dies.—One of the many designs for universal notching dies is illustrated in Fig. 89.   The sketch is a plan view.

The scheme is to shape the die opening so that by using a properly fitted punch, various contours can be cut into the edges of previously prepared blanks.   The shaded portion of the sketch, shown in the die opening, represents the heel on the punch, which prevents punch deflection and consequent damage to the cutting edges.
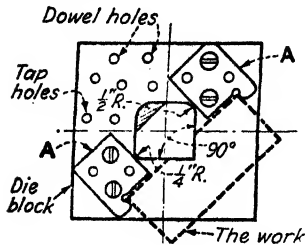
Fig. 89.—An extra large die block having many tapped holes and dowel pin holes can be used for securing gages *A*, where desired, for locating and notching a particular blank.

The prepared blanks may have been cut in a first-operation blanking die or possibly are of rectangular shape, sheared off as shown in Fig. 91.   The die block is made unusually large.   The idea is to provide space for many tapped holes and dowel-pin holes, used for attaching a varied number of special gaging blocks for locating the sides or ends of any peculiarly shaped blanks that the die might be used for.   This is an excellent tool for the small shop.   It often saves the time and expense that might be otherwise uselessly expended in the design and construction of special blanking dies.

The sketch shows a square corner cut in the side of a rectangular blank while it is located between gages *A-A*.   With two or more of these tools having varied shapes in the die openings, the outlines of an endless variety of blanks can be cut.   For instance, the blank for a
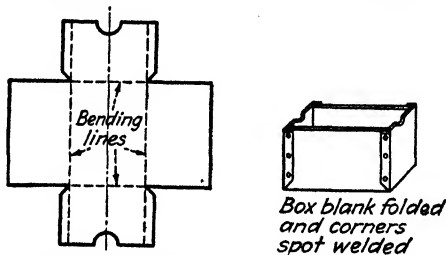
Fig. 90.—A blank for a steel box was first notched with a universal notching die, then folded up in forming dies, and finally spot-welded together.

steel box (Fig. 90), is made in a similar tool.   Folding of the blank into a box is done in a universal forming die.

Ingenuity is required in designing and arranging special gage blocks to get certain blank contours from these tools.   The tool is used mostly for small orders.   Commercial machines have been highly developed for doing similar work on a large scale.   These are called "turret punching machines."

Universal notching dies are now made commercially and can be quickly obtained for cutting a large variety of contours, both round and

square.   The price is probably less than the cost to the user who attempts to make them, if he includes his overhead expense.

Shearing Rectangular Blanks.—Most well-equipped pressrooms have a universal shearing die.   The principle of the tool is seen in Fig.
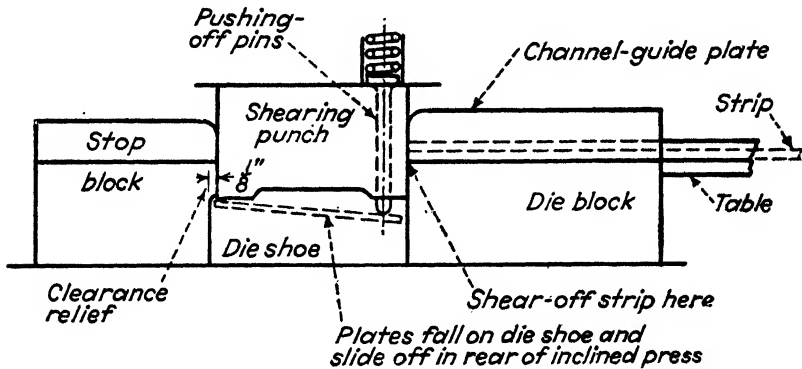
Fig. 91.—Universal shearing dies are fitted with an adjustable stop block for cutting rectangular blanks of various widths.

91.   Such dies can be made adjustable by arranging the stop to slide within a retaining slot, toward the right or left, and securing it rigidly with heavy clamp screws.

In this design, the tool can be quickly set up for shearing different widths of rectangular strips.   The lengths of the strips are limited by the width of the die and by the width of the material sheet.

The sketch and accompanying notes show the idea plainly.   If the die block is provided with die bushings and corresponding piercing punches, holes can be pierced in the blanks at the first station.   The punches are backed up with screws, and any of the screws can be loosened for the purpose of raising the punches when the corresponding holes are to be omitted.

Fig. 92.—Dinking dies (the one shown is a hand tool) can be mounted singly or in multiple in power presses for cutting shapes from thin sheets of nonmetallic materials and soft metals.

"Dinking Dies."—Hand tools, called dinking dies, are extensively used for cutting blanks from paper, cardboard, thin celluloid, soft rubber, felt, leather, thin fiber, and soft sheet metals.   The sheet to be cut is placed on the end grain of a hard wooden block, and the die is placed over the sheet and is forced to cut

the blank by mallet blows on the shank.   A hand dinking die is shown in Fig. 92.

Hard rubber, fiber, Micarta Plate, and similar materials are readily cut after heating to a semiplastic state in a hooded gas oven.   For accurate blanks, however, an allowance is necessary for heat expansion and contraction in cooling.   Although there are fairly accurate formulas for shrinkage allowance, it is best to determine the shrinkage by trial, because much depends upon the grade of the material and the relation between the surface area and the thickness of the blank.

Dinking dies for cutting heavy materials are provided with a standard punch shank for securing the die in a power press.   A shedder plate is fitted loosely within the die with a knockout rod passing vertically through the shank.   For cutting multiples of thin blanks in one press stroke, several dinking dies of even heights are attached closely together on a punch plate affixed to the ram.   A shedder within each of the dies is either a spring plate held by stripper screws or a soft rubber pad cut fully within the die.   Interlocking the dies closely avoids wasting the material.   This setup in a press is a dangerous one for the operator's fingers and should be fully protected by safety devices that control the clutch operation.

Dinking dies are used extensively for shaping leather goods and especially in cutting the outlines for mittens and gloves.

TYPES OF BLANKING DIES

Blanking Die with Channel Stripper.—Figure 93 illustrates the usual design for a plain blanking die with a positive channel-stripper
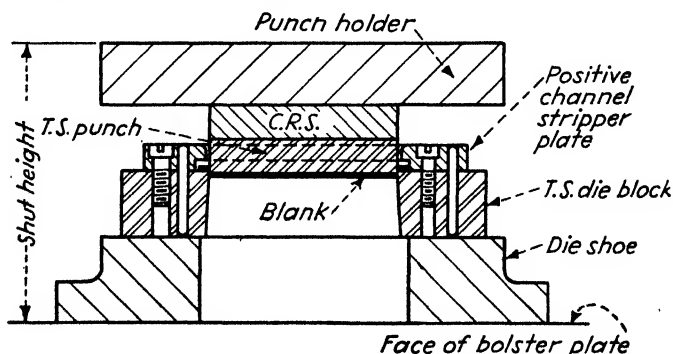
Fig. 93.—Plain blanking die with positive channel-stripper plate.

plate attached on the die block.   This design is least expensive of all blanking dies.   It is the type most commonly used and will stand up under hard use until worn out.   This is a "drop-through" die, in which

the cut blank falls out through the die block, shoe, and bolster plate. When the ram ascends, the punch, having been cut through the sheet, carries it up and strips off the scrap frame under the roof of the channel. In large blanking dies, both the punch and the die members are usually backed up with a cold-rolled steel filler plate, to complete their heights. This feature saves the expense of making solid blocks of tool steel, as is done in smaller dies.

Blanking Die with Spring-pad Stripper.—This die, shown in Fig. 94, is the same design as the one just described, except that it employs a spring-pad stripper plate. The spring pad contacts the strip ahead of the punch and holds the material flat just before the blank is cut. In cutting large blanks of thin material, the spring-pad pressure removes all the waved irregularities in the sheet. When the ram
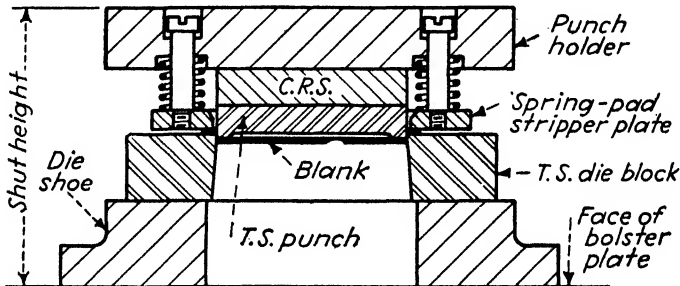
Fig. 94.—Plain blanking die with spring-pad stripper plate.

ascends, the spring pad strips the scrap frame from the punch without raising the sheet from the die.

Another advantage in using this design is that the work performed is in full view of the operator and not covered by the stripper plate, except at the moment of blanking. In a die that uses a spring-pad stripper, the cut blank can be forced back into the strip, as illustrated in the next figure.

Returning a Blank into the Strip.—For large work this method will dispose of the blank more easily in cases where the press-bed opening is not large enough to permit the blank to drop through. For small work the returned blank can be carried forward in the strip, for additional operations at succeeding stations.

In Fig. 95 the die is shown closed, and the blank cut. When the ram ascends, a spring shedder under the blank forces it up against the punch face, and the spring pad holds the scrap frame on the die, while the shedder pushes the blank back into the scrap opening whence it came.

There are several ways to remove the blanks after returning them into the strip.   Large blanks, cut in a straight-side press, are knocked
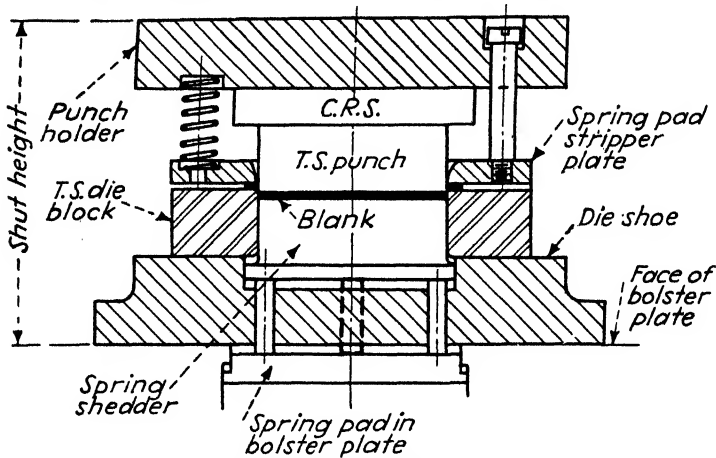
Fig. 95.—Blanking die in which the blank is returned into the strip, when the punch ascends, by the pushing action of a spring-shedder in the die.

out by a second operator at the rear of the machine.   Smaller ones can be ejected through a clearance hole by the descent of a suitable punch. If the blanks are long and narrow, with lengths positioned across the strip, they can be ejected by passing the strip over a roller.
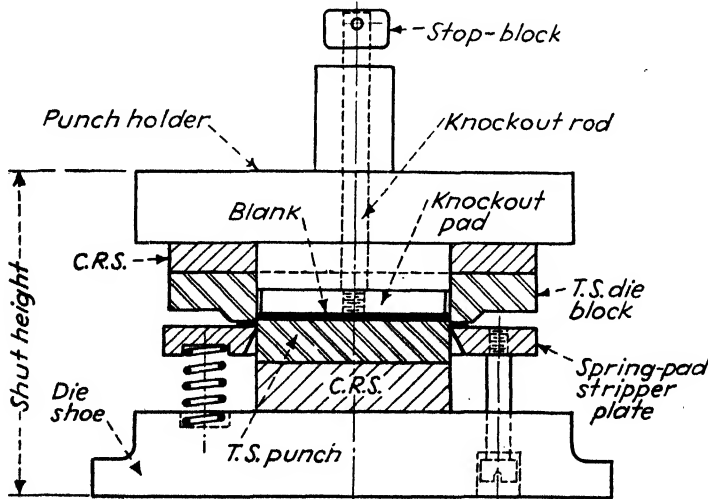
Fig. 96.—Inverted blanking die with spring-pad stripper and a knockout pad.

Inverted Die with Knockout Pad.—Figure 96 is a completed drawing of the diagram sketch given in Fig. 77.   This die is used on presses

where the opening in the press bed is too small for dropping through the blank. Both the punch and the die heights are built up with .cold-rolled steel, which is economical in the use of tool steel.

The coiled compression springs under the stripper pad are not placed around the stripper screws but are placed in separate recesses, as shown. This permits using longer springs than possible to use if they surrounded the screws. Coiled springs will "stand up" longest when not compressed more than two-thirds the difference between
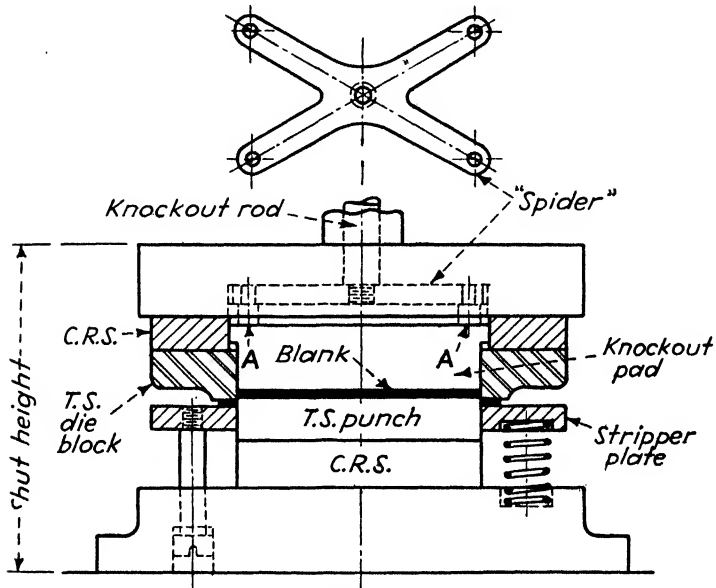
FIG. 97.—Inverted blanking die with spring-pad stripper and a knockout pad in the die, actuated by horizontal spider arms.

their free lengths and solid heights. In low-production dies more than this allowance can be safely used.

This type of die can be mounted on a bolster plate having no openings and on a press of minimum-size bed opening. Therefore, for heavy operations, this design eliminates much of the "tool spring" and vibrations noticeable in conventional drop-through blanking dies.

When the ram ascends, the blank, having been cut into the die, is ejected by the knockout pad and its attached rod, at the moment, in ascent, when the stop block over the end contacts the press bar.

Knockout Actuated by a "Spider."—For long, narrow, or large blanks of unusual shapes, a knockout spider is employed similar to the one sketched in Fig. 97. A spider is used for widely distributing the pressure points on the pins at A; thus the knockout pad ejects the blank

evenly all around its periphery. Slots are milled in the punch-holder face, of sufficient clearance widths to permit free working action of the spider arms. The spider is cut from structural-steel plate with an acetylene torch and smoothed by freehand filing or grinding. The diameter of the knockout rod is made larger than usual to cause the spider to operate horizontally at all times.

Fig. 98.—Sketch of a perforated blank produced in a single-station compound inverted die.

Knockout Spider for Compound Dies.—Figure 98 represents a blank that must be pierced and cut with its edges and hole centers positioned within the limits of precision accuracy; therefore a compound die must be employed. This die uses a spider knockout, and the design is seen in Fig. 99. It is advisable in such cases to ascertain whether or not there is a sufficient surface of metal on the face of the punch holder, after cutting the spider slots, to back up punch *A*, for cutting hole *B* in the work. This
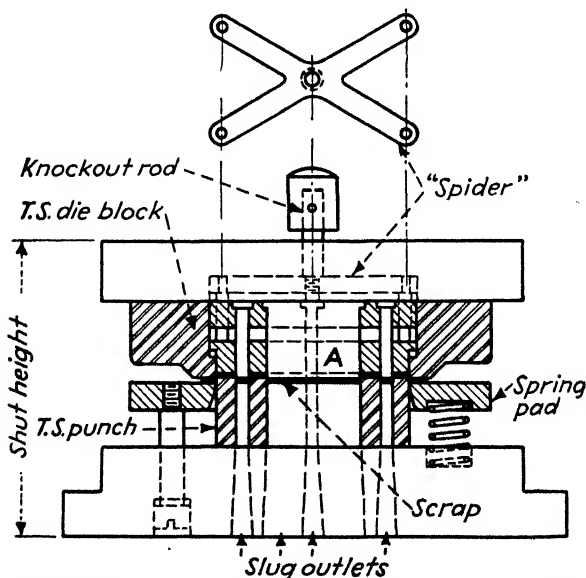
Fig. 99.—Inverted compound die with spring-pad stripper and a knockout pad in the die, operated by horizontal spider arms.

determination is made by sketching the central portion of the spider across the work, as shown in Fig. 98, in which four spaces are exposed where screw and dowel holes can be inserted.

The accuracy of compound dies depends entirely upon the skill of the toolmaker and his experience in constructing high-precision dies. The principle of compound-die accuracy is that all the holes are pierced and the blank is cut simultaneously at a single station. The compound action in piercing and blanking this part is clearly indicated in the section view of the die. At the shut height of the tool, the upper punches are shown cutting and pushing through the slugs; the blank itself lies on the face of the lower punch which cuts the blank outline into the die above.

Removing Cut Blanks by Hand.—When notching and cutting off long blanks under a positive-type stripper plate attached on the surface of the die block, it is possible to arrange the die so that the operator can pick off the blanks by hand at the left of the tool. This, of course, refers to dies that are used in gap-frame presses. Many such tools have an extended table at the left upon which a movable stop can be positioned for cutting off a variety of lengths.

The following die design is used only when a few hundred blanks are to be run occasionally. The stripper plate is constructed with an open front. The width of the table is made so that a margin of the blank projects over its edge in front of the operator. The margin provides a finger hold, and the cut pieces can be lifted off with the left hand. For high production, a spring stripper plate is mounted around the punch, the press is tilted back, and when the ram ascends, the cut blanks slide off at the rear of the machine.

CHAPTER XII

TWO-STEP DIE OPERATIONS

Piercing, Stamping, Shearing, and Notching Operations May Be Followed with Blanking, Cutting-off, or Other Cuts and Indentations Performed at Consecutive Stations

Introduction.—"Tandem dies," or "follow dies," perform one operation at a first station, which is simultaneously followed by another operation immediately after advancing the strip into a second station. The finished pieces that pass from the die come from a single row. Tandem dies and follow dies are sometimes called "progressive dies," but this name is not usually applied unless the consecutive stations are more than two.

Piercing and blanking dies are sometimes constructed for as many as 10 parallel rows of blanks. These dies are for special cases, however, in which the blank is a very simple one and the piece is small but has a very high production. The piercing and blanking of washers, small nut blanks, spool heads, and terminal buttons are examples.

In precision work, the accurate locations between the consecutive die stations and their relative position to the longitudinal center lines of the die and strip are very important distances to have right. It is therefore a practical necessity in modern diemaking to locate all the die centers in one setting of the block, on an *accurate* jig-boring machine. The word "accurate" is used advisedly; it implies that even a jig-boring machine may sometimes be out of line, after long usage and wear.

This also directs our attention toward probable inaccuracies in other machine tools around the shop, especially those used more than 10 years. Perfect work cannot come from imperfect conditions, unless by an accident, and such accidents never happen around machinery. The bearings and "line-up" of all machine tools should be carefully checked occasionally.

Shearing, Forming, and Cutting-off Die.—Figure 100 shows a piercing, shearing, forming, and cutting-off die in which the principle of shearing predominates. The work is shown in Fig. 101 and is called by radio manufacturers a "grid-shield." After piercing one hole in the first station, the strip is advanced over the 1¾-in. length of pres-

sure pad, which is normally flush with the die, until the end of the strip contacts the stop block shown at the left. The strip enters within a U-channel in the stop.
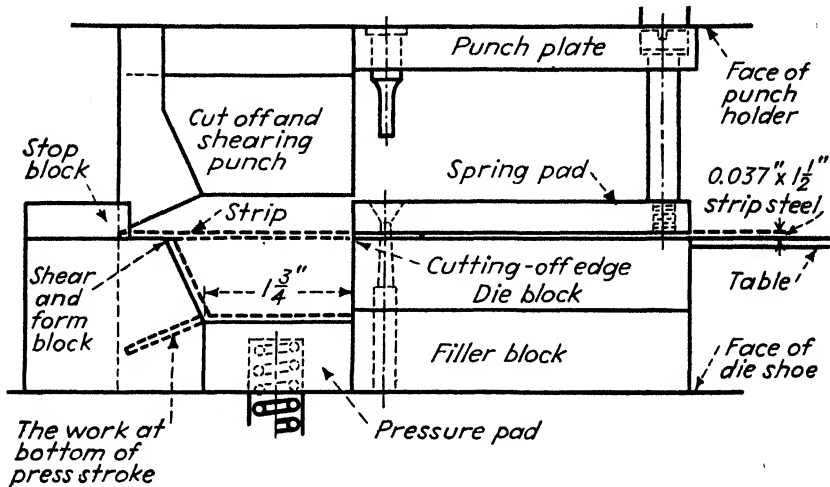
Fig. 100.—The grid-shield shown in Fig. 101, is pierced in the first station, and, in the second station, sheared 1 in. deep on the center line parallel with its edges, and the split-apart wings are then bent in opposite directions by the faces on the shearing punch.

When the ram descends, the forward point on the cutting-off and shearing punch starts shearing the strip lengthwise against the shearing block. The cut is kept straight by the U in the stop block. The pad pressure begins when the punch, continuing in descent, cuts off the strip on the left edge of the die block. A further descent of the shearing punch completes the depth of the cut on the shearing block and simultaneously forms one sheared wing *up* and the other one *down*. The formed wings are "spanked" straight when forced by the punch faces against the angular faces on the shearing block. This occurs at the moment when the pressure pad registers on the die shoe at the bottom of the press stroke.
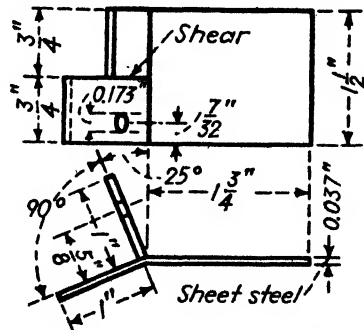
Fig. 101.—The radio grid-shield.

Removing Pieces with Vacuum Tips.—When stamping or cutting off small pieces of work and even quite heavy pieces, they can be removed from the die after the operation by using a soft-rubber vacuum tip mounted on the end of a compression spring punch. In

the downstroke the rubber tip engages on the piece by suction, and the reverse stroke carries up the work for removal by an overhanging finger, or "sky hooks." The piece then falls behind the press.
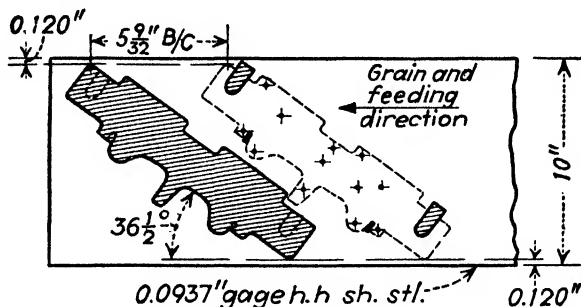
FIG. 102.—At the first station, punches with backing-up heels cut the four narrow salients before blanking; in the next station, the blank is completed by a punch that cuts across the previously made salients.

Eliminating Frail Inserts in Dies.—Frail projections within a die should be eliminated to avoid breakage. Figure 102 shows a scrap-strip design for removing the salients within a blanking-die opening. The desired cuts are produced in the first station by punches provided

FIG. 103.—Four salients are cut in the blank shown, without using frail projections or inserts in the die.

with backing-up heels. When the strip is advanced over the blanking die, the salients are cut across by the descent of a blanking punch provided with pilots, and the finished blank appears as shown in Fig. 103. By using this method, expensive inserts are avoided in the die. Frail inserts will not "stand up" for continuous cutting of heavy-gage sheet metals. All the die openings for piercing and blanking are shaded in the sketch. The straight dotted lines in Fig. 103 represent the bending lines where subsequent forming will occur in the piece.

Two-step Stamping and Shearing-off Die. A type of shearing-off die is shown in Fig. 104. This tool stamps the lettering and pierces two mounting holes in a name plate and then shears the plates to length in the second station. The sketch clearly shows the operation.

An improvement in this tool is to introduce a spring pad between the shearing edge on the die block and the stop block at the left. The shearing punch should be the same length as the pad. The sheared-off

pieces are blown off the pad by compressed air; or by inclining the press they slide off in the rear. The die set used is a standard type with two posts in the rear.

Piercing and Shearing-off Die.—Figure 105 illustrates a shearing-off die for cutting strips from wide sheets of heavy material. This operation is not so simple as it first appears. The stock is ⅛-in.-thick sheet steel 30 in. wide, and the cut strips are 3 in. wide by 30 in. long. The operation is performed in a large straight-side press, and the stock is therefore fed from the front to the rear of the press.

Positive stop A must be high enough above the surface of cutting block B to act as a backup for the cutting-off punch C before it begins
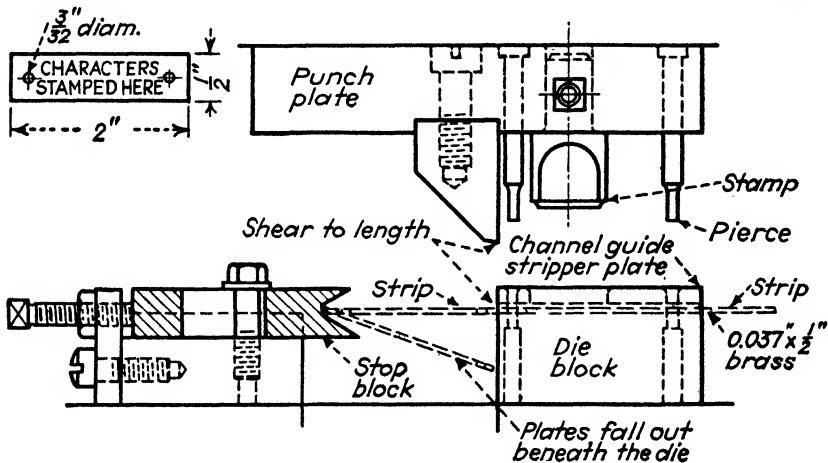
FIG. 104.—In this shearing-off die, stock is fed against the stop block for piercing and stamping at the first station and for shearing off at the second station.

to cut. A spring pad D is necessary under the cut strip to hold it in a horizontal position during the cutting interval. The spring pad prevents the work from tipping on its cut-off edge as an axis, which would result in cutting an angular edge not wanted.

However, this design has a serious fault; when the punch ascends, followed by the cutwork on the spring pad, there remains no way in which to remove the strip automatically, and the stock cannot be fed forward for the next cut. The previously cut strip interferes. The strip is too long, and the die is positioned the wrong way in the press to facilitate pushing out the strips endwise.

These difficulties are overcome by attaching one hinged latch hook F at each end of the punch holder, which, in the downstroke, will "hook" under the ends of the work. These hooks have a 20-deg. slant in their hooking surfaces. Therefore, when the hooks ascend with the

ram, they lift the sheared-off strip from the pad and, continuing upward, lift the work above the top of the backstop, allowing it to tip to the 20-deg. angle and to slide off the inclined delivery table as shown.

If desired, a perforating operation can be made at the right of the cut in the oncoming strip, as indicated by the punch *E* and stripper plate *H* in the sketch. The face of the cutting punch is ground to a shearing angle of a height about the thickness of the material used.
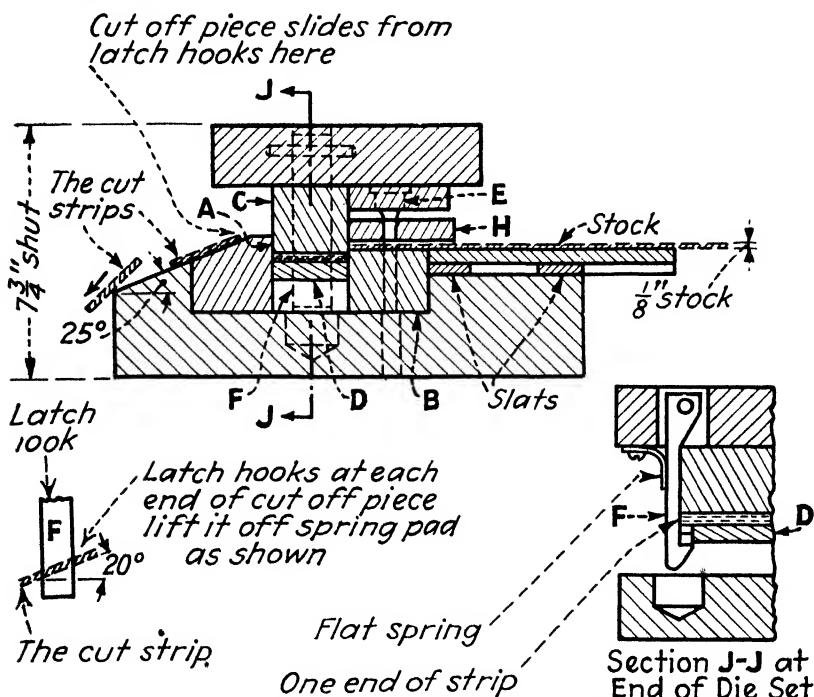
Fig. 105.—Several difficulties in operating this die for shearing off strips from wide sheets are overcome by the latch hook *F* which, in ascent, lifts the cut strip above stop *A*, and allows it to slide down the ramp at the left.

The shearing angle starts at the center of the punch and extends each way across the sheet to be cut. This slight shear does not distort the strip. A frame of angle iron and cross slats 34 in. long and the proper width is constructed on the right-hand side of the die shoe for guiding the sheet up to the tool.

Pierce, Notch, Cut-off, and Form Die.—This tool is a four-station die. It is introduced here to show how several consecutive operations can easily be added in two step dies and thus produce more work. Other progressive dies of this type are treated at length in the next chapter.

The progressive notching die notches or trims a blank from either side of the strip and leaves the blank and strip attached by a small neck. The blank and strip are then passed along into successive stations where all varieties of die operations can be performed. These dies are high-speed producers of small parts and are very satisfactory if properly designed and constructed. Dies of this type are well
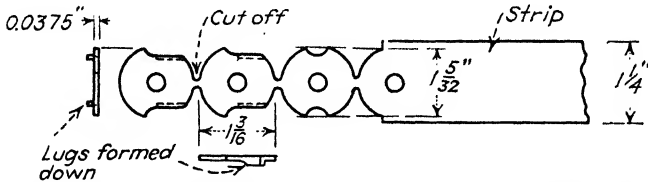
Fig. 106.—Many varieties of small work are performed in progressive dies, of which this strip is a sample of how a typical sequence of operations is performed.

known in connection with high-speed presses and with multi-slide and dieing machines. In Fig. 106 are three views showing typical operations on a strip taken from one of these dies.

In progressive dies, the blank and strip are often, but not always, the same width. There is no scrap frame to pass out of the die after the piece is made. The scrap is simply small slugs and notching waste
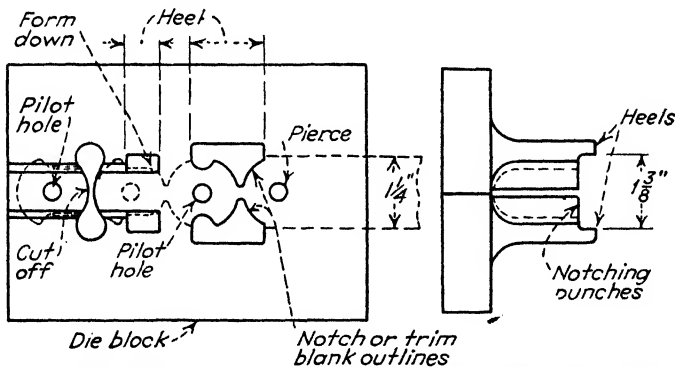
Fig. 107.—Notching punches in progressive dies must have a heel that enters the die before the cutting edge contacts the strip, thereby guiding the punch, which prevents shearing or nicking of the cutting edges.

and perhaps a narrow cutting-off waste across a small connecting neck between blank and strip. The pieces made are small clips, brackets, and terminals or connector lugs, all of which are of light-gage thicknesses. The sequence of operations may be: notch, pierce, emboss, draw, form, and cut off. The number of working stations may run up to 8 or 10.

In the first station, when the ram descends, two punches cut out-
lines of the blank, one punch at each edge of the strip, leaving a small
connection to the strip.   A pair of notching punches are sketched in
Fig. 107.   The important feature is the heel on the punch which enters
the die opening ahead of the cutting edges.   This precaution protects
the sharp edges from shearing off or nicking, as might otherwise be
expected from an unbalanced cut such as notching.   The heel guides
the punch into the die and prevents punch deflection in three direc-
tions and thus prevents damage to cutting edges when taking "biting-
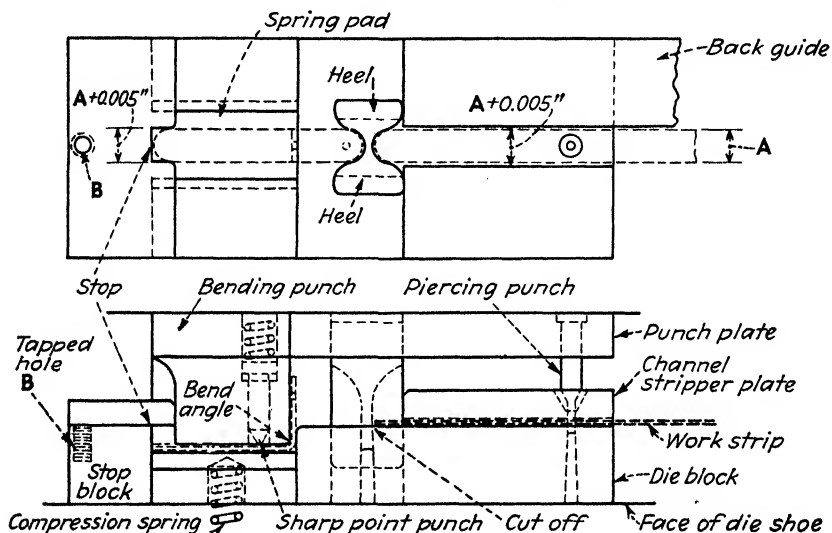
Fig. 108.—When the ram ascends, the completed piece follows on the spring pad
and is raised flush with the die surface.   The piece then falls out at the rear of the press,
which is inclined for that purpose.

in cuts" which would otherwise certainly occur without the safeguard
of backing heels.

In this die, the lugs are formed *down*.   When forming lugs *up*, the
strip is raised $\frac{1}{16}$ in. by passing it up and over a small open channel
ramp on the die face.   In the next descent of the ram, a forming punch
"throws up" the lugs between the inner sides of the ramp.   A "push-
off pin" underneath the forming station, and another one within the
forming punch, frees the work for the next advance of the strip.   These
types of progressive dies are sometimes called "cut-and-carry dies."

Cutting Off and Bending Dies.—A piercing or notching operation
can be added at a first station in dies of this design.   The principles
involved in simultaneously cutting off and bending a right angle in
strip, flat wire, or strap stock are presented in Fig. 108.   Since the strip

must be severed before bending the blank, the face of the cutting-off punch must be located *ahead* of the bending-punch face. This distance should be equal to, or more than, the thickness of the strip.

The face of the piercing punch must be of a length considerably *less* than that of the cutoff punch. If the cutting-off and piercing punches enter the strip together, the inevitable "kickback" of the strip, when cutting off, may either break the slender piercing punch or cause it to nick when it enters the die. Time must be allowed, after severing and before piercing, to enable the operator to push the cut end of the strip forward against the right-hand side of the cutting-off punch.

Before severing the strip, the face of the bending punch contacts and holds the strip *down* on the spring pad. Sometimes a sharp-pointed spring punch is designed to engage and align the strip prior to cutting off and bending.

Dies of this design can be arranged to cut off and form many lengths of pieces by simply attaching the revolving stop plate shown in Fig. 109. A shouldered fulcrum screw is placed through the center hole in the plate and into the tapped hole *B* in the stop block shown in Fig. 108. Dowel holes *D* (Fig. 109) are intended for locating the plate on the stop block at any desired gaging position.
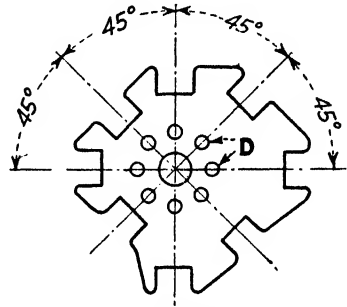
Fig. 109.—This revolving stop gage for eight lengths of work can be made to accommodate many other lengths of work by making a plate of larger diameter and adding more stop notches.

Material Strip with Angular Entering End.—In a piercing and blanking die of two or more stations, the entering end of the material is sheared at an angle corresponding with the slant of the die opening across the strip. The angle is shown in Fig. 110, at *A*, and the die openings are section lined for clarity. If a square-end strip enters the die, one or more of the first blanks is waste. In addition to the waste, the blanking punch would cut only a portion of the blank in the second station and would thus be caused to deflect and to chip off cutting edges.

The strip enters the die and is stopped in the first station by depressing finger stop *B*. The angle across the strip provides the means for piercing both holes at this station. When the stop is released, it recedes to its normal position because of compression spring *C*.

In the next move, the strip is advanced into the second station either against another finger stop, not shown, or against the registering point on automatic stop *D*. The strip is then ready to be run through

the die with the "press open," that is, with the clutch treadle constantly depressed.

In progressive dies having several stations, three or more finger stops are sometimes needed for starting in the strip. This is often
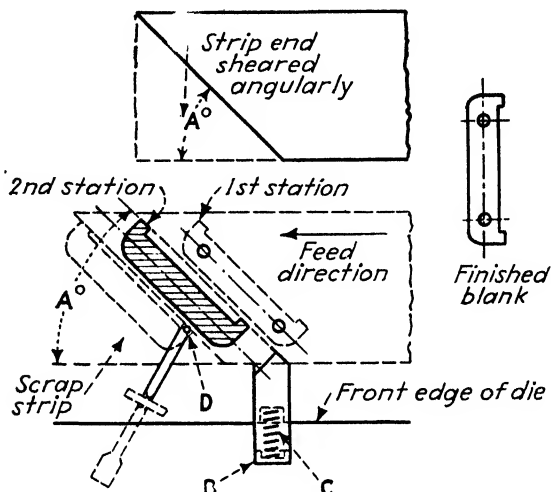
Fig. 110.—For this type of pierced and blanked strip, the entering end of the material is sheared off obliquely, and a finger stop B is employed to avoid wasting the first blanks and to prevent incomplete cuts that might deflect the punch and nick cutting edges.

found necessary for peculiar-shaped work, even though the end of the strip is square or sheared off at an angle.

Two-step Die with Scrap Cutter.—Figure 111 shows a scrap cutter built into the die itself. The cutter is simply an auxiliary punch which severs the scrap frame on the left edge of the die block, as shown.
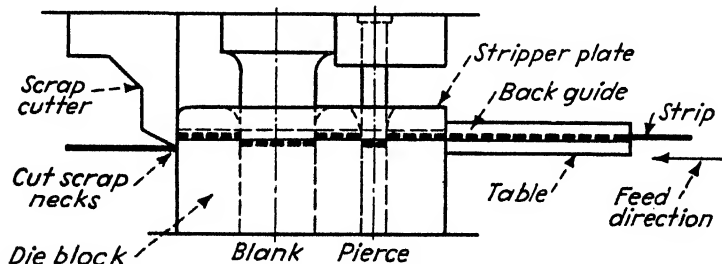
Fig. 111.—Piercing and blanking die with scrap cutter attached.

In Fig. 112, two or more scrap cutters can be arranged in large dies, and the left edge of the die block designed to facilitate cutting through the necks of odd-shaped scrap frames.

Scrap cutters operate at each press stroke and therefore sever the scrap into blanking-center lengths. They are used at the left of dies in gap presses and at the rear of dies in straight-side presses. A barrel or box is placed to catch the pieces.
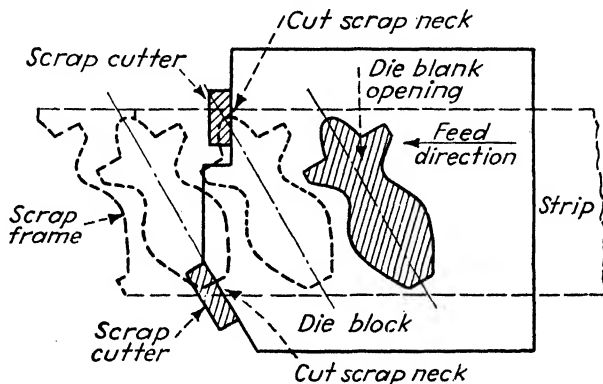
Fig. 112.—Large blanking die provided with two scrap-cutting punches for severing the necks of an odd-shaped scrap frame.

Bushings for Small Holes in Dies.—Small holes—round, square, and elongated—should be enclosed within hardened and ground bushings. The interiors of the bushings should be lapped to size. High-speed tool-steel bushings and piercing punches are usually best.

For subsequent changes and replacements and to compensate for distortion of the die block in hardening, bushings are necessary, especially in precision die work. In dies large enough to allow space for attaching them, commercial piercing punches and dies, such as Richard Bros. and Whitman & Barnes, can be used. Removable piercing members are subject to easy changes; they can be taken out, and other sizes or shapes substituted.

Removable Punches and Dies for Piercing.—A method for removing punches and die bushings, if broken, or for substituting other sizes, is sketched in Fig. 113. This principle is applicable in any punch plate or die block in which piercing members are used.

A hole is drilled and tapped in the punch plate, leaving a wall $\frac{1}{16}$ in. thick between the threads and punch body, as shown in the figure. This wall is partly cut away or slotted at the top, to admit a $\frac{1}{4}$-in.-diameter steel ball. The sides of the ball slot are enclosed at angles of 5 deg., as seen at A. This design allows the ball to protrude into the hole for the punch and to be retained there at less than one-half its diameter.

A headless socket screw, having a concave point, forces the ball into the 15-deg. annular groove cut in the punch body. Tightening the

screw locks the punch by forcing it up against the hardened disk, shown above the punch. Press vibration will not loosen the screw, because its side pressure against the ball "side locks" the threads. The die bushing is held in the manner just described, and either of the cutting members can be replaced without removing a heavy die from the press.

This device will hold punches and bushings that are very close together, a condition difficult to solve with any of the commercial
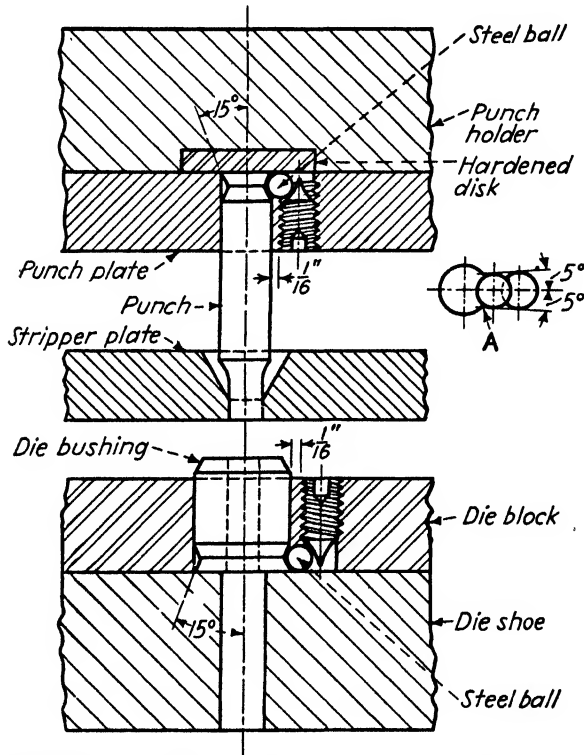
Fig. 113.—A design for removable piercing punches and dies that can be easily made by any toolmaker.

devices made for this purpose. In the device under discussion the locking screws can be placed in any position around the members to be locked. The retaining ball cannot fall on the wrong side of the screw point, because there is insufficient space to allow it. A "hex-pointed" wrench with a right-angle bend is used to operate the screws.

Slug Clearance Slots under Die Bushings.—When pierced holes are too far removed to allow the slugs to fall through the press-bed opening, a slug-delivery slot can be cut in the die shoe, leading from underneath

the bushing, as illustrated in Fig. 114. The slot may be extended into the bolster if necessary. In operation, the slugs are delivered through the slot by gravity and press vibration and out in front of the
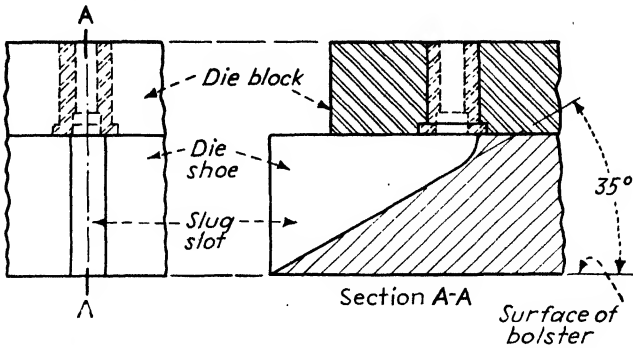
Fig. 114.—An angular clearance slot, cut in the die shoe, leads the slugs from under a die bushing and out on the bolster plate.

die shoe on the surface of the bolster plate and are then swept off occasionally.

Fastenings for Small Punches and Bushings.—For punches and die bushings that pierce holes of shapes other than round, a positive
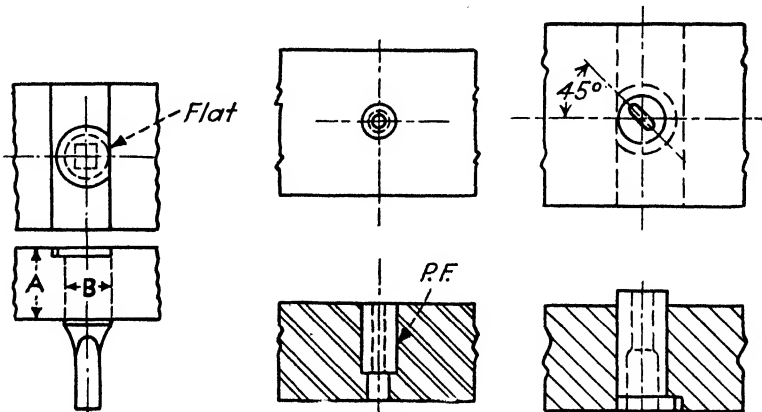
Fig. 115.—A rectangularly faced punch is prevented from turning by cutting a flat across the edge of its flange.

Fig. 116.—A die-bushing press fitted in the die block.

Fig. 117.—A die bushing with a portion of its flange flattened to prevent it from turning.

fastening is necessary to prevent them from turning. The following methods for securing punches and bushings applies to one or more perforators in two-step dies or to 100 punches and die bushings mounted in large perforating dies.

The square-faced punch in Fig. 115 cannot turn because one edge of its body flange has a flat edge which fits snugly against the edge of a slot milled across the punch plate.   For all perforators mounted in a punch plate, the thickness of the plate *A* should be approximately 1½ times the punch body diameter *B*, when possible.   This condition provides the best permanent "line-up" for small punches.

Bushings in small dies are press fitted in the die block, as seen in Fig. 116; but for piercing holes other than round in large dies (Fig. 117) the bushing has a flat across its flange which fits against a "slot edge," the same as for punches.   Other methods to prevent die bush-
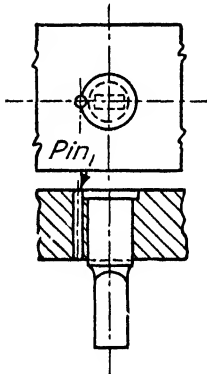
FIG. 118.—A rectangularly faced punch secured by a "dutchman" dowel pin.
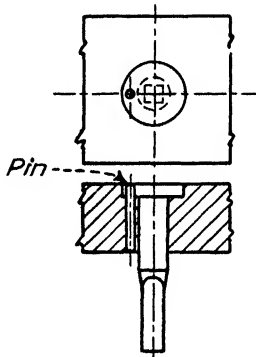
FIG. 119.—A rectangularly faced punch secured by a dowel pin inserted through its flange.
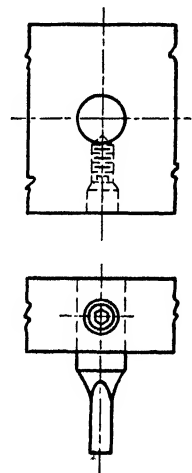
FIG. 120.—A piercing punch held by a conical-pointed setscrew.

ings from turning are the same as those shown for the punches in Figs. 118, 119, and 120.

In Fig. 118 the punch is prevented from turning by inserting a "dutchman pin" half through the punch flange and wholly through the punch plate.   This design is not thought to be as permanent a fastening as using a larger flange and inserting a dowel pin entirely through the flange and plate, as shown in Fig. 119.   Figure 120 shows an inexpensive punch fastening used in low-grade dies.   The point on a setscrew is forced into a "spot center" in the body of the punch, and the flange is omitted.   In using the latter method, however, trouble may be encountered in the radial alignment of the punch with its corresponding die.

Standardizing Hole Diameters for Bushings and Punches.—The punch plates for high-grade dies are made of tool steel but left soft. For large perforating dies, the punches are held in cold-rolled or machinery-steel plates. The die blocks for large perforating dies can be made of cold-rolled steel with the holes "bushed" with hardened bushings. In this die-block design, the holes do not change in shape or position, because the block is not hardened.

If the outside diameters of the die bushings and punch bodies are made equal, as shown at D in Fig. 121, the holes in the punch plate and die block can be bored simultaneously with the plate and block clamped together. This idea saves much time and diemaking expense.
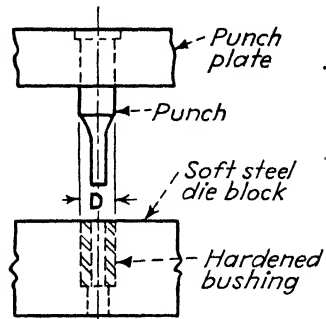
Fig. 121.—A soft-steel die block with a hardened steel bushing inserted. Diameters D are equal for the punch body and die bushing. This idea facilitates boring the plate and block while they are clamped together in one setting.

Removable Stop Pins.—In many types of dies, removable stop pins are necessary. This is particularly true in trimming dies and certain perforating dies in which several blank sizes must be trimmed or pierced in the same tool. Figure 122 shows a design for a removable pin that serves the purpose. Tightening the screw draws up the nut wedge, spreads the split prongs of the pin body, and locks the pin securely in place. By simply loosening the screw, the pin can be quickly removed and placed and locked in another hole. This principle is useful in other cases where pins, studs, or posts must be quickly secured and released in different holes.
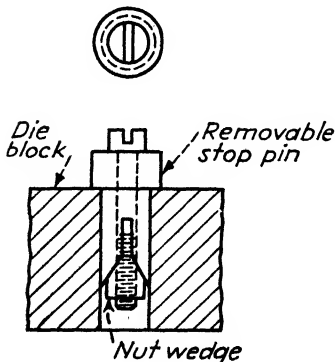
Fig. 122.—A simple and effective design for securing a removable stop pin.

Arc Welding Punch Blades on Flanges.—In dies for large work—harvester and automotive parts—the tool members are arc welded together wherever possible. In Fig. 123 at A is a large punch blade arc welded to a cold-rolled steel flange. The rigidity and permanency of small welds for securing parts together is indeed surprising. More recently, in light manufacturing, they have been welding together small punches and flanges, as shown in Fig. 123 at B.

In dies for high continuous production, such as for electrical-instrument parts, the flange is low-grade tool steel, whereas the punch itself may be an expensive high-carbon, high-chrome die steel. Where a large number of dies are in use, welding saves considerable labor time and material expense. A built-up punch of welded-together parts is practically as good for sustained high-speed press operations as though machined from one piece of expensive tool steel. In expert arc welding, the temper of hardened punches is not drawn if the operation is quickly done and proper cooling precautions taken. It is noticed at C, in Fig. 123, that the weld unites the pieces by melting into the corners slightly. Before loose pieces are welded, they must be placed together in desired positions and then clamped securely in a fixture.
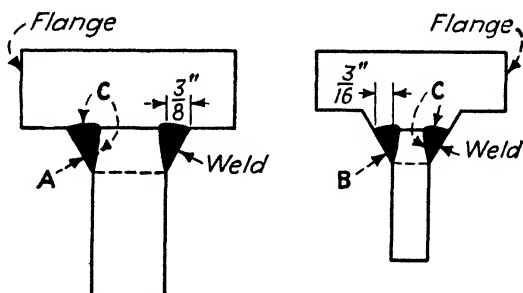
Fig. 123.—Large or small punches can be arc welded onto low-grade steel flanges as seen at *A* and *B*. At *C*, the weld unites the pieces by melting into the corners slightly. This method saves material and hardening costs, and also machining time.

High-grade dies for continuous runs use a special high-chrome steel in which the carbon content is about $1\frac{1}{2}$ per cent. There is also a small addition of vanadium and molybdenum. This type of die steel will attain its maximum hardness by air cooling. It is practically a guarantee against cracks and distortion where intricate shapes are involved in hardening. Its deformations under heat-treatment are probably less numerous than those encountered in most other types of die steels.

DOUBLE-ROW BLANKS, STOPS, AND REAR REGISTRY OF STRIPS

Piercing and Blanking Double Rows.—A simple progressive die is the two-station pierce and blank type shown in principle by Fig. 124. The usual stripper plate over the die is removed to expose the plan. "Step," or blanking, centers of the die and strip are the equal distances *B/C*. Section-lined holes represent section views through the punches. Round holes within the blank opening and sectioned in reverse order are section views through the pilot pins that protrude from the face of

the blanking punch. These pilot pins register, just previous to cutting the blank, in the two holes pierced at the first station.

This die is designed for double-row blanking. A finger stop is necessary to facilitate entering a new strip. In this case, one stop serves for starting both rows of blanks. If the finger stop is omitted, the operator may enter the strip too far. He then cuts only a partial blank and may fracture the pilot pins or shear and nick the punch and die edges. At other times, he may not insert the strip far enough. In either case the first blank is wasted.

Fig. 124.—If the pierced holes are not accurately located with respect to the blank outline, the press tool must be checked for construction errors.

When the finger stop is depressed, it withholds the forward end of the strip at $\frac{1}{64}$ in. from the nearest cutting edge of the blanking die, as dimensioned in the sketch. When the "bridge" of metal between the blanks is sufficiently large, $\frac{1}{32}$ in. or more is allowed from the blanking edge to the stop face. This allowance is intended to take care of cases in which the end of the strip is slightly out of square with its edges. But where comparatively long and narrow blanks are run bias in the strip, it is sometimes necessary to shear off one corner on the forward end of the strip to clear the blanking die and pilots. Thus, a full cut into the metal for the first blank is obtained, as shown in Fig. 110.

When the end of the strip engages the depressed finger stop, in Fig. 124, the press is "tripped," and only the two holes are pierced.

The operator then releases the stop. A compression spring forces it back, from over the die, to its normal position as shown. The strip is then advanced against the positive stop pin. The punch then cuts the first blank, with the pilots engaging previously pierced holes.

The strip is now ready to be run through the die with the press "open." This means that the tripping pedal is depressed and not released until the first row of blanks has been competed. The stop-pin design can be any one of those described under Figs. 61, 62, 65, and 66.

When the first row of blanks has been "run out," the strips are sheared on line *D-D*, making dimension *a* and *A* equal. The second
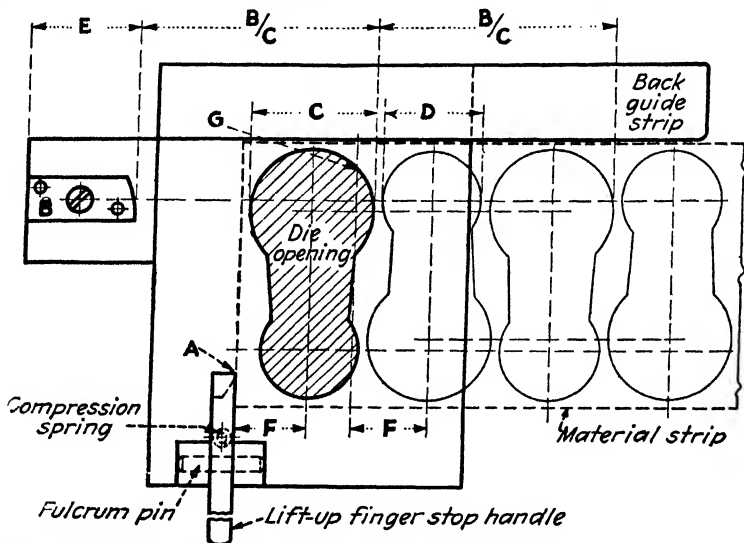
Fig. 125.—Blanking operations on some automobile bumper guards are handled by this type of scrap strip and stop layout.

row is then pierced and blanked but from the reverse side of the strip. However, shearing off the strip ends can be avoided by installing a second finger stop, left of the present one and at a distance of $A + a$ from the first station.

Double Row of Alternate Blanks.—A method of arranging stops for two rows of large alternate blanks is shown in Fig. 125. Here the strip is in position for blanking the first row. The first and second rows of blanks are not "staggered" in the strip, as are those shown in Fig. 124. The second row is cut from alternate spaces remaining between the blanks made in the first row. Strip width is the same as used for a single row. The finger stop is normally elevated above the material strip by a compression spring. When the stop handle is lifted, the

forward end of the strip is stopped at point A. After the first blank is cut, the finger stop is released, and the first row is run through the die.

Positive stop B is located to suit the blanking centers. The width of the blanked opening C is greater than the width D. Therefore, the length E of positive stop is made greater than D and less than C. This feature facilitates running the second row of blanks when the strip is turned over. The smaller openings D slide across the length of the stop, but the right-hand edge within the larger openings C falls against the stop and registers as desired.

Point A on the finger stop is located at the lower part of the blanked openings at the position where dimensions F are equal. When the strip is turned over to start the second row, A is caused to contact within the first blanked opening at point G, and the strip is then run through the die in the same manner as described for the first row. Blanks of these shapes favor using stops of this design.

Forcing Strips against the Back Guide.—In operating blanking dies, it is sometimes necessary that the rear edge of the work material positively contact the back-guide strip across the rear of the die. This condition is imperative in all cases where the width W of the material strip and the width of the finished blank are equal, as seen in the "cut-and-carry" die (Fig. 126). In this design, the work strip is forced against the back guide automatically by descent of a heeled and pointed cutting punch A, just prior to piercing and blanking. The point on edge B is slightly curved upward, as shown, to aid in forcing back the work strip. The point on the punch enters the front edge of the stock $\frac{1}{64}$ in. and ahead of all other punches.

Another device used to force the strip automatically against the back gage is given in Fig. 127. The principle involved is simply a sheaved roller, mounted on a spring-tensioned bell crank. The roller bears against the front edge of the strip. It should be observed, however, that the pointed punch in Fig. 126 allows free feeding, whereas the roller pressure causes friction on the strip against the back gage. If the friction interferes with feeding, a cam punch can be arranged to free the bell crank and roller momentarily, while the stock is being advanced. Freeing the strip momentarily is also done in automatic roll-feeding mechanisms, to allow the punch pilots, in descent, to enter freely and register properly in the pierced holes of the work.

Punch Clearances.—In blanking dies, the die opening determines the size of the blank, and punch clearance is removed from the sides of the punch. However, for perforated holes, the punch determines the size, and punch clearance is removed within the die opening.

In other words, the punch determines the size of the hole it passes through, and the die determines the size of the blank that passes through it.

These rules apply to average piercing and blanking for accurate work, but an exception was described under Fig. 75. Another exception: A pierced hole is actually 0.002 in. smaller than the punch that passed through it; this allowance should be made for high precision work. When large thin blanks are cut from waved sheets, that is,
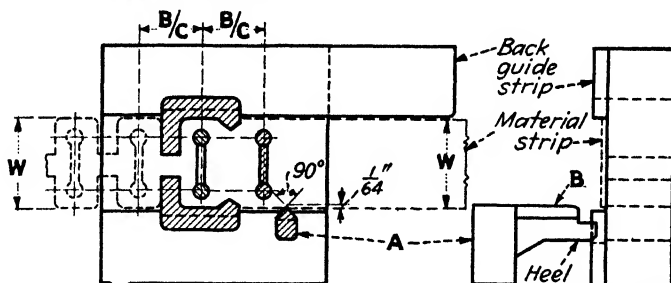
Fig. 126.—A pointed cutting punch *A*, contacts the strip edge before other punches, and registers the strip firmly against the back gage of the die.
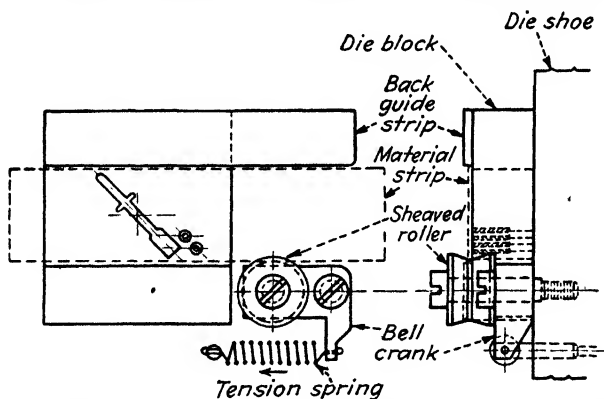
Fig. 127.—A sheaved roller can be used to register the strip against the back gage, but the friction produced may interfere with hand feeding.

when the sheets have not been "leveled" or "stretched," such blanks will pass through the die, although they are actually larger than the die opening itself.

Sheared Cutting Faces.—Sheared punch faces greatly diminish the blanking pressure but cut oversized and distorted blanks. In most cases, the shearing angles are ground on the die face in preference to the punch face. If ground on the die, blank distortion is very small. Sheared cutting edges are necessary in cases where the blanks are comparatively large relative to the gage thickness of the sheet.

CHAPTER XIII

PROGRESSIVE DIES

Progressive Notching, Perforating, Embossing, Drawing, Forming, and Cutting Off Are Done in a Single Press Tool by Carrying the Evolving Part Along in the Strip

Introduction.—The fabrication of metals in dies includes blanking, notching, piercing, trimming, splitting, shaving, broaching, burnishing, embossing, drawing, expanding, forming, bending, swaging, extruding, squeezing, sizing, cutting off, and several other minor operations. Although any of these operations is comparatively simple to produce, yet when they are combined at several stations in progressive dies, it often becomes difficult to devise the most practical and economical scrap strip design and the best mechanical operation for the tool.

Cutting dies compose the largest class of press tools. They all involve only one principle: shearing; but in combination cutting dies, we often encounter unusual complications. Progressive dies still present a number of unsolved problems; one of them is to dispose of the finished piece in the last station where two formings and cutting off are to be done. It is usually best, in such cases, to finish the last forming operation in a separate die.

Another problem is to design a practical equalizing device to guide the strip through the dies; this is especially difficult where the punches interfere with the operation of the equalizer. A practical equalizer is not yet discovered for guiding coiled strip having a variable camber curve in its opposite edges. Another difficulty in progressive dies is found when attempting to run large work of heavy-gage materials.

Progressive Compound Dies.—Design principles for a progressive compound die are shown in Fig. 128. This press tool approaches the "cut-and-carry" type. The operations shown can be performed in light-gage stock from 0.025 to 0.065 in. thick. As shown, A and B are the die shoe and punch holder; C is the die block; D is a spring stripper plate attached to B; E is the work strip; F is the blanking punch; G is a forming punch which carries a work-locating pilot pin; H is a punch that pushes the finished piece out of the strip; and J and K are spring-ejecting and forming shedders, respectively.

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The shape of the blank is seen in the scrap strip above the drawing. The blank is pierced and cut in station 1. Pierced slugs are cut through F and fall out through the slanting hole L, which leads out at the rear. Spring plates M compress the shedders J and K, and upon the ram ascent they push the cut blanks back into the blanked openings in the work strip before the spring stripper plate relieves its pressure on the strip. Stations 2 and 4 are idle, but the cut blank rides over them while held in the strip. Idle stations provide a sufficient space between the die operations to allow attaching the punches and provide additional metal between die openings where there is insufficient strength. The blank is relocated by a pilot in forming punch G and is formed by
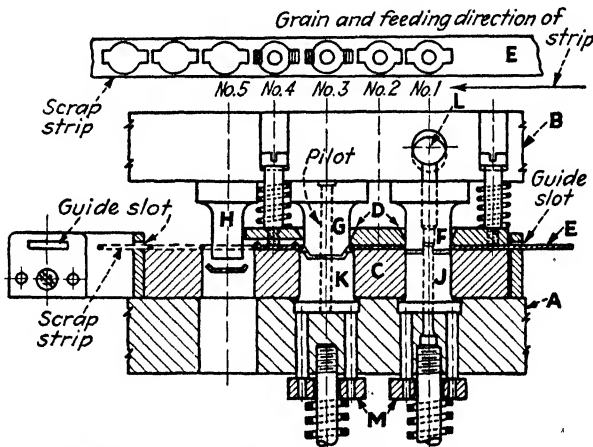
Fig. 128.—A progressive die in which the blank is cut through the strip and then replaced in the strip by a spring shedder and pad. The finished piece is finally ejected from the strip by punch H in the last station.

punch G against shedder K, while the latter registers in the die shoe at the bottom of the press stroke.

After the work passes beyond punch G, a clearance channel cut in the stripper plate allows for passing along the formed-up wings on the pieces in the strip. At station 5, the finished work is pushed out of the strip by the descent of punch H, and the work drops through clearance holes in the die and shoe.

Open-faced dies, like the one shown, have no positively attached channel stripper plate through which to guide the strip. The strip is therefore guided through slots in vertical plates shown attached at the ends of the die. If the work strip is not mechanically fed, a vertical automatic finger stop can be placed at the left of the punch H for hand feeding. This type of compound die is a high-speed tool for blanking and forming certain small parts from thin-gage materials.

"Cut-and-carry" Dies.—The principle of cut-and-carry dies is to perform all operations while passing the strip through several consecutive stations on the surface of the die block. The blank is notched to shape from either or both sides of the strip by heeled punches. A small connecting neck is left between the blanks which serves to advance them, with the strip, from station to station.

The object in using this type of progressive die is to secure maximum economy of strip, high speed, and uninterrupted production. Simple parts, and some very complicated ones, can be completely fabricated in one pass. In spite of extra cost, cut-and-carry dies are profitable. With them it is possible to fabricate a piece in one press operation that could not be done satisfactorily by any other known method.

When the width of the blank and strip are equal, cut-and-carry dies are sometimes called "no-scrap dies." In this case no scrap frame is passed out of the die. The scrap consists of small perforated slugs and notching waste. Sometimes, but not often, there is a narrow cutting-off waste. The work pieces are usually small springs, clips, brackets, terminals, or connector lugs of light-gage materials.

Fig. 129.—The first step in designing cut-and-carry progressive dies is to unfold the finished work piece into a blank development.

One drawback with these dies is the difficulty in using them for large work or for materials exceeding about 0.0625 in. gage. Heavy materials require time to fabricate. If distorted, heavy blanks cannot be realigned, by using registering pilots, so easily as with thin flexible strips.

Sequence of operations for cut-and-carry dies may be: notch, perforate, emboss, draw, form, and cut off. Forming is done either before or just after cutting off. It is sometimes advantageous, however, to form one or more operations before severing the piece from the strip; a final forming can be done in the last station simultaneously with cutting off.

Before designing a suitable cut-and-carry die, the finished piece in Fig. 129 must be unfolded into a blank development. This procedure gives the developed width of strip and shows the size, shapes, and positions of all the necessary die operations. Next, lay out the work-plan view in red dotted lines, and show consecutive die operations as in the upper view of Fig. 130. Also draw the cross-sectioned die openings. Project the front elevation below the plan in a shut position. Draw the views schematically. Show all necessary punches, die openings, and spring shedders that correspond to the several stations in the plan.

Developed width of strip

Split through terminal ends

Ramp

Ramp

Horizontal cams

Punch holder face

Strip thickness

Die block

Die shoe face

Heel

Sprg.

Sprg.

Push off pin

Ramp

Sprg.

Pilot

Sprg.

Sprg.

Arbor

Vertical cam

45°

45°

Fig. 130.—The blank development leads to the die plan shown above, and a preliminary sketch of the tooling as shown below.

A preliminary sketch of the future die is now well in hand. This is the tentative stage of the tool, or a *discussion sketch*.

Naturally, the die operations are arranged in logical order: perforate; notch and emboss; split sever terminals and pierce embossure; form U between ramps; pilot; cut out connecting neck and form over the sides with horizontal cams, and "spank" to size. An exact sequence is (1) perforate, (2) notch, (3) emboss, eject strip with die shedder, (4) split sever terminals, (5) pierce embossure and eject strip with die shedder, (6) form U between ramps and eject strip with die shedder and with a push-off pin in punch, (7) pilot, (8) cut out connecting neck *A*, (9) advance horizontal arbor cam *B*, form over sides with the opposite horizontal cams *C-C*, and spank work to size with punch *D*. The side cams *B* and *C-C* are loosely fitted vertically to allow movement for spanking. The work is advanced through the stations by means of the connecting neck *A*.

The next step is to determine the position of several necessary finger stops and the type and position of the automatic stop. This subject has been discussed under Fig. 124. The channel stripper plate is not shown, but it should cover the entire width of die and terminate between stations 5 and 6. The die block is abnormally long, and its points of sectional divisions must be determined. The piece is usually blown off with air, if possible, but sometimes this cannot be done because the cams interfere. A suggestion for work delivery is to strip the piece from cam *B*, as it recedes, and to provide a clearance hole through the die into which the work will fall.

Positions of the angles on the vertical cams that operate *B* and *C-C* must be "timed" to advance arbor *B* ahead of *C-C*. Note that the vertical cams, at maximum descent, lock the horizontal cams by means of the dwell space *F*. When the ram ascends, the horizontal cams are caused to recede to a normal stop by attached springs, not shown. The problems that arise in each cut-and-carry die are different. The practical solution for some of these problems is so obscure that it may be necessary to make an experimental die station to pre-solve the difficulty in the toolroom.

Several problems must be solved for this tool. For example, in splitting through the terminal ends, the work may not register the same at each advance, and a small notch, or protrusion, may appear on the blank after splitting. The remedy, if one is necessary, is to allow sufficient stock at this point to shear off a width slightly greater than the stock thickness. The amount sheared off must obviously be added between the blanking centers. This alteration would increase the cost

of both the work material and the tool.   However, a rectangular pilot punch can be made to enter slot E, before splitting, and would take care of the difficulty, at a slight increase in expense.

When using positive pilot punches there is always a danger that the piloting hole has not been previously pierced in the strip and that the pilot will smash the work when the ram descends.   This condition is likely to occur when a new strip is entered into the die.   To avoid such accidents it may be necessary to use a compression-spring pilot or to install a finger stop to halt the strip and thus ensure that the first pilot hole is pierced.

0.040" brass
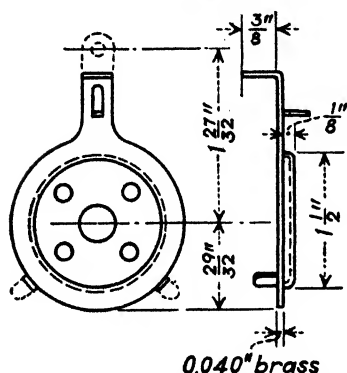
Fig. 131.—A depression 1½ in. in diameter by ⅛ in. deep in the part indicates that drawing should be the first operation in a progressive die.

Another consideration is grinding. The part of the die block that carries cutting edges must either be "shimmed up" after grinding, to maintain its level with the forming blocks, or the forming blocks must be ground underside to keep the block surfaces in the same plane.   This indicates that there must be a division between the cutting and forming blocks.   Another suggestion is: It may not be necessary to use spring shedders to raise the strip from the forming blocks; a trough cut along the horizontal center line of the blocks will clear the embossing on the work.   These questions show the value of making a "discussion sketch."   They reveal the necessity for carefully analyzing each operation.

In high-precision cut-and-carry dies, when the piece is too complicated for a complete finish in one pass, it is better to form the final operation in a separate die.   Thus, a frequent breakdown of the tool or inaccurate work pieces may be avoided.   Do not attempt to produce too many operations in one tool.

This die and others of its kind require the long narrow types of die sets.   Select a set with a generous margin around the die blocks to provide for possible additions.   It may be found necessary to attach an equalizer later or bell-crank rollers to force the strip against the backguide, or additional stations and a feeding device may be required.

Arrangement of Progressive Die Stations.—Figure 131 gives the principal dimensions for a part made in large quantities in a progressive die.   The material is 0.040-in. brass, and one of the operations is a depression 1½ in. in diameter and drawn ⅛ in. deep.   In the layout
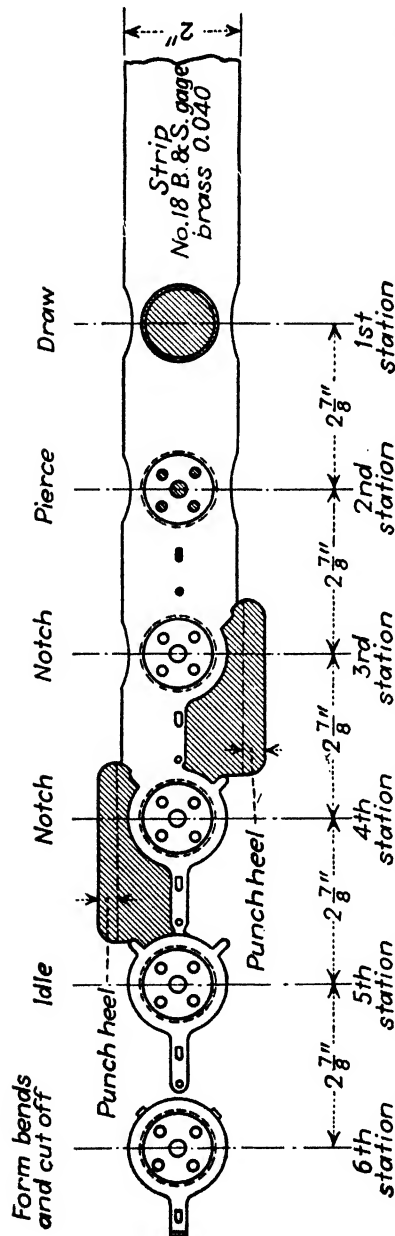
FIG. 132.—It is good practice to locate notching punches in progressive dies for narrow work, so that they are not opposite. Thus is avoided a narrow neck in the die that would be troublesome in machining, hardening, and upkeep.

of the strip (Fig. 132) it is quite clear that the drawing operation should be first and that the piercing, trimming, cutting off, and forming should follow in the order named. Drawing operations distort the strip and for this reason are done first so that the cutting operations that follow will not be deformed. The positions of all the die openings are section lined for clarity.

It is good practice to "bush" the small holes in all die blocks if possible; this precaution facilitates changing hole sizes if desirable and makes it possible to relocate the hole if the die blocks have changed after hardening. The trimming punches are not located opposite because the neck in the die, between the nearest cuts, would be too narrow for hardening successfully. The precautions to be observed in these designs are the same as those given on the typical scrap strips for multi-slide machines (Figs. 155 and 156).

Other types of cut-and-carry progressive dies are illustrated and described under Figs. 106, 107, and 126.

Check List for Die Designers.—One way to improve the quality of finished dies is to keep a record of any and all punch and die failures for use as a reference by the tool engineer, diemaker, and inspector, thereby preventing the recurrence of previous mistakes in design. Although the causes of die failures are many, it has been found that about 50 of the more common failures probably cover 98 per cent of the total.

The following list is made from such a record of die failures. It is arranged in numerical order, each number being a reference to the die shown in Fig. 133. When studying this design, bear in mind that an attempt has been made to show as many different types of construction as space will permit; in practice, some of these details would not be necessary.

1. *Spring Life.*—Spring failure is common; but when springs of ample length and strength are used, little trouble is encountered. The average spring can be compressed 25 per cent of its free length safely.

2. *Removable Pilots.*—If possible, pilots should be removable, as shown in Fig. 133, to facilitate grinding the punches.

3. *Provision for Grinding.*—The spacer pieces shown provide a means of keeping the relative length between these two punches and the rest of the punches by grinding the same amount off each at each sharpening of the tool. There are many conditions such as this, and various ways of getting around them. Each should be studied, and the best method selected.

4. *Thickness of Punch Plate.*—Punch plate must be of ample thickness, particularly when punches are not guided in the stripper.
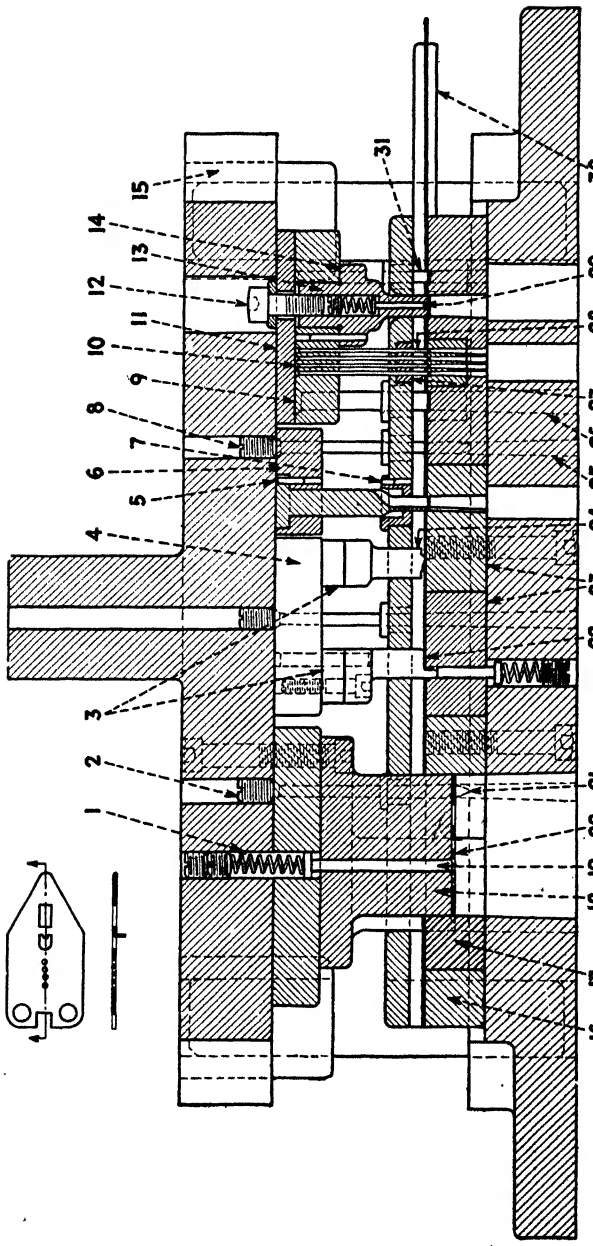
FIG. 133.—The numbers refer to the accompanying check list of factors to be given consideration in die design. (*Courtesy of American Machinist.*)

Punches of ½ in. diameter cannot be properly supported in a plate less than ¾ in. thick.

5. *Punch-shank Location.*—For radial location, a dowel through the head of a punch is more positive than the "dutchman" which goes half in the shank and half in the plate.

6. *Punch-plate Material.*—As the punch plate is left soft, one is inclined to think it can be made of any material. This is not so, particularly when accurate boring of holes is necessary. The best grade of tool steel should be selected for such plates.

7. *Guiding Delicate Piercing Punches.*—A delicate punch like this must be guided as near as possible to the work. This can be done by a plate set in the bottom of the stripper (see No. 26) or with a bushing as shown. Grinding life is sacrificed to make a punch that will not break in use.

8. *Spring Pilots.*—Occasionally it is necessary to put springs behind pilots for various reasons. This should be avoided if possible.

9. *Piercing Small Holes in Thick Stock.*—Piercing punches held in a thick punch plate backed up as shown and guided in stripper bushings will punch holes in material 30 to 35 per cent thicker than its own diameter. The shank, however, should be at least twice the diameter of the hole being punched, and the cutting end must be the hole size for only about two thicknesses of the material. Here punch life is sacrificed to gain strength.

10. *Angle on Headed Punches.*—About 60 deg. included angle seems to stand up best. In high-grade dies, punches should be held by square-shouldered heads turned integral with the punch body, as seen in Fig. 84.

11. *Hardened Plate under the Punch Plate.*—This construction is often advisable to prevent small punch heads from sinking into the punch holder which will eventually fracture the head, causing the punch to pull out.

12. *Holding Punches.*—This method of holding a punch eliminates the necessity of hard-driving fits and is desirable in some cases.

13. *Sturdy Unguided Piercing Punches.*—It is advisable or best to guide punches in the stripper in most cases. Sometimes it cannot be done very well. In these cases sturdy punches such as shown here will stand up well.

14. *Grinding Punch Shanks.*—All punch shanks should be ground to the proper drive or tap fit. Drive fits tight enough to keep the punch from pulling out should be avoided. Punches with heads (or screws, see No. 12) need only be a snug fit in the hole, in which case no trouble will be encountered in assembling or disassembling.

15. *Die-set Bushings and Pillars.*—The designer should give some thought to the requirements of the particular die in question. On precision jobs cutting thin stock, extra-long bushings help line-up. Four pillar sets are often advisable. A little study on each job will determine what is best.

16. *Die Thickness, or Life.*—This is a point to be considered, and the designer should note carefully what the production requirements are and establish the ideal thickness for that purpose.

17. *Insert Weak Places.*—All delicate projections on a die should be inserted for economical replacement in case of breakage. (See Fig. 195.)

18. *Punch Life, or Length.*—This note pertains to the various conditions that govern the practical length of the punches. In general, of course, we like to have enough to allow for many resharpenings. Often punch length must be cut to a minimum to attain maximum strength. This design shows the blanking punch long enough to push each blank clear to eliminate distorting the bent lug.

19. *Holes for Push-off Pins.*—Before hardening of blanking punches, it is well to drill somewhere a hole in which can be inserted a spring push-off pin in cases where blanks pull up. (See Fig. 76.)

20. *Must Each Blank Be Pushed Through?*—Where a blank has a bent lug as shown, the designer must provide a long punch to push each part clear. This is not advisable unless necessary.

21. *Is Piloting Condition Good?*—The success of a progressive die depends largely on the pilots. Special holes for pilots in the scrap are advisable in most cases, even though it increases the cost.

22. *Bending Wrong Way of Grain.*—The designer will sometimes slip up on this. It is well to have this reminder, because when it happens it is apt to be a costly mistake.

23. *Has the Die Sufficient Sections?*—A separate section for each station is a safe rule to follow when designing progressive dies. Sometimes, of course, even more than this is necessary.

24. *Should the Die Have Bumper Blocks?*—If the die should accidentally be closed too far with no stock in place, stamps and short-life punches will be damaged. To avoid this, screw one or two spacer blocks in the rear of the die just high enough to fill the space between the die shoe and the punch holder (tools closed). This will also make the setting up of the tool an easier task. It is a good rule to put these spacer blocks on every expensive or complicated progressive die. (See Figs. 80 and 243.)

25. *Scrap Holes for Pilots.*—Because of occasional misfeeds, pilots will push scrap down into the pilot holes; therefore, these holes

should be carried all the way through and taper reamed, as shown, to allow the scrap to go through.

26. *Proper Condition of Scrap Holes in Die Bed.*—Just making the scrap holes larger than the slug is not the answer. Slugs have a way of stacking, catching, and wedging. Cast-iron die beds may have small blowholes, which make perfect little steps on which these stacks of slugs start piling. If holes are smoothly taper reamed and have no steps or pit holes, the slugs will never jam. Steel bushings can be inserted if a blowhole exists. (See Fig. 81.)

27. *Punches Closely Spaced.*—Where space does not permit bushings in the stripper, a hardened insert such as shown should be provided. If precision spacing is required, the location of holes must be corrected after hardening by grinding.

28. *Wire Punches.*—Much can be said for or against this economical type of piercing punch which is made of drill rod, hardened and head-upset, or peened, by hammering. Although it must be guided in the stripper, it will stand up quite well where the diameter of the hole to be punched is $1\frac{1}{2}$ times the thickness of the stock. If the diameter is less than $1\frac{1}{2}$ times, the head is liable to crumble, and the punch will pull out when stripping.

29. *Push-off Pins in Piercing Punches.*—As with the blanking punches, it is advisable to provide a hole in which to insert a push-off pin in case slugs are inclined to pull up and prevent feeding the strip.

30. *Stock Guides.*—If possible, guide the stock; the length of the guides should be twice the width before the first operation. Rollers, springs, and various construction should be used to suit the requirements.

31. *Keeping Small Piercing Slugs from Pulling Up.*—This note pertains to punches too small for push-off pins. Particularly when piercing hard stock, slugs will at times have a tendency to pull back up into their holes, thereby hindering the feeding of the strip. If the hole diameter is two or three times the material thickness, this can usually be stopped by pointing the punch slightly like the point of a nail.

When the ratio is less than this, pointing will not help. However, slugs can be prevented from pulling up by cutting down on the clearance between the punch and die and making the hole in the die straight (no draft) for about two thicknesses of stock at the top of the die. In obstinate cases it is necessary to develop the proper clearances between the punch and die by experimenting with different clearances until the slugs stick tightly in the die.

Operating Details of a Progressive Die.—Figure 134 shows a sheet-brass float arm and its corresponding blank development. The mate-

rial is 0.0625 in. gage.   Figure 135 shows two schematic views of the progressive die in which the piece is made; it sets forth the cut-and-carry principle.
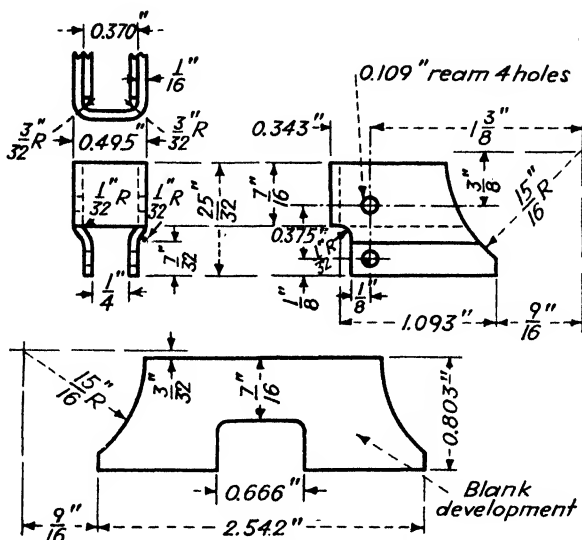
Fig. 134.—Float arm and blank development. This part is produced in the single-operation progressive die. (Shown in Fig. 135.)
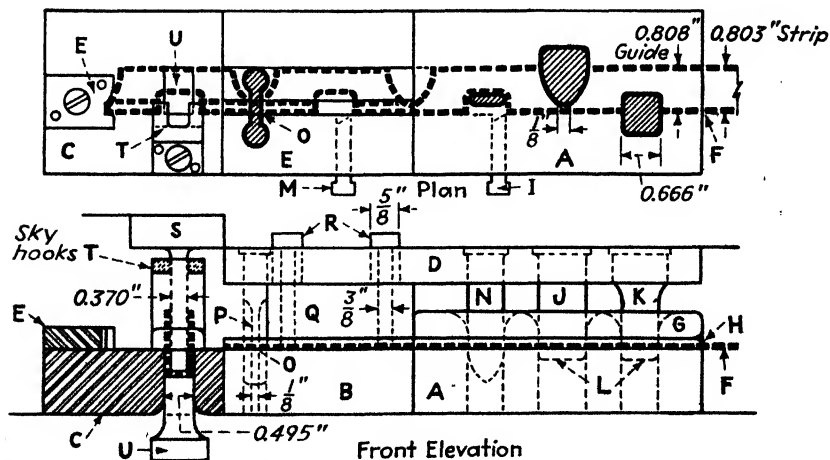
Fig. 135.—Progressive die for notching, forming, cutting off, and "throwing up" the wings on a float arm.   One piece is finished at each press stroke in this four-station die.

The tool members *A*, *B*, and *C* are independent die blocks, and *D* is the punch plate.   The material strip *F* is purchased in large rolls, the width of the material being the same as the developed width of the

blank.   A positive-type channel stripper plate G is anchored in place on the die face, the channel width being 0.005 in. wider than the material strip that is to be guided through it.

The strip roll is vertically mounted on a ball-bearing floor reel at the right of the press, and the strip, as it unwinds from the roll, passes through a commercial "hitch-feeding" device (not shown) and enters the die through the stripper channel at H.   With the hitch feed disengaged, the end of the strip is inserted by hand and is stopped at the first finger stop I, when the stop is depressed.

As the ram descends, punches J and K, each with backing heels as shown at L, notch the strip edges to the $^{15}\!/_{16}$-in. radius and 0.666-in. dimensions, respectively.   Punch J leaves a neck of metal in the strip $\frac{1}{8}$ in. wide, as shown in the die plan.   The neck connects the successive blanks but is eventually cut out as waste.

In advancing the strip by hand into the second station against the depressed finger stop M, and tripping the press, the bullet-nose pilot punch N enters the previously notched 0.666-in. opening and positively registers the strip.   After the ram has ascended, the operator engages the hitch feed, and the tool and work are ready to run automatically.

In automatically advancing into the third station, the strip passes over the cutting-off die O, where it is severed by the descent of the punch blade P.   This cut removes the $\frac{1}{8}$-in. neck of metal between the blanks.   The half portion of the first blank, at the left of the blade, is waste.   In the third station the forming of the offset, consisting of two $\frac{1}{32}$-in. radial bends, also takes place, accomplished by the descent of the forming punch Q which shapes the bends against the forming die B after the forward blank has been severed.

Inserted through punch Q are two "push-off pins" R, each of which is actuated by a compression spring in the punch holder.   The faces of the pins normally project beyond the faces of the cutting and forming punches and in descent contact and hold the strip securely just previous to the cutting off and forming of the piece.   These push-off pins also serve to hold the work on the die face when the forming punch ascends.

As the strip is advanced into the fourth and last station, its cut end enters the opening shown in stop block E.   The contour of the opening is the same as that of the end of the strip; thus the work is necessarily aligned and accurately positioned before the two wings are formed.

In the next descent of the ram, the final forming punch S slides between the two sectioned prongs shown at the top of "sky hook" T, contacting the surface of the blank at the instant of severance.   Continuing in descent, the punch forces the work to fold within the

0.495-in. opening in die *C* and seats the folded piece firmly against the face of a strong spring resistance pad *U*, which is a sliding fit within the die opening. This action "throws up" the two wings on the piece within the opening and against either side of the punch.

As the punch continues downward, it forces the bottom of the pad to register positively in the die shoe at the instant of maximum crank stroke. This action "spanks" the formed wings to an exact angle of 90 deg. to the bottom of the piece and, therefore, parallel with each other.

When the ram ascends, the work is carried up with the punch, owing to the action of the spring-pressure pad beneath it. Continuing
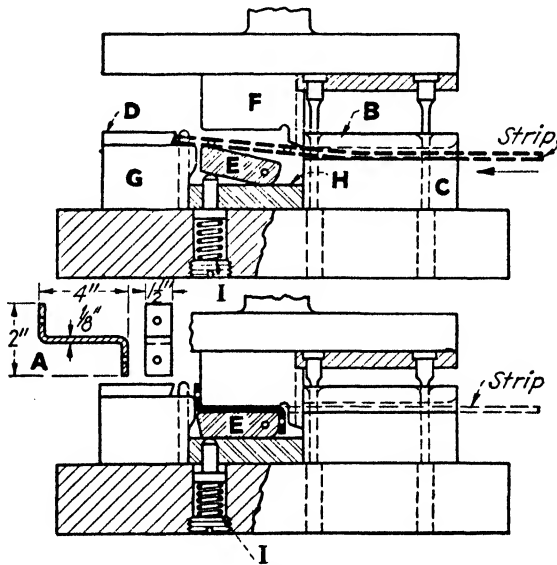
Fig. 136.—In this progressive die the cut blank is confined between the edges of *C* and *D*. This holds the blank while the bends are located accurately.

in ascent, the pad eventually resumes its normal position, with the pad face flush with the die faces. The work, still adhering to the punch, is finally stripped off when it contacts sky hook *T*.

The press being tilted toward the rear, the pieces fall by gravity into a container placed behind the machine. The four 0.109-in. holes must be perfectly aligned and for this reason are subsequently drilled and reamed in a jig.

Progressive Pierce, Cut-off, and Forming Dies.—Figure 136, at *A*, shows a steel bracket to be pierced, cut off, and formed with two angular ends, one piece per press stroke. The single-operation progressive die is shown in two views. The upper view shows the punch

members ready to descend and cut off, pierce, and bend the ends of
the work in opposite directions.   In the lower view, the tool is com-
pletely closed, and all the operations have been finished.   Such tools
are built in a great variety of designs for rapidly producing such small
articles as radio parts, telephone switchboard braces, and brackets for
assembling furniture.

The strip is fed through a channel stripper plate *B* and across the
face of the piercing and cutting-off die *C*.   The left end of the strip
registers against stop *D* and is positioned over the pivoted forming
block *E*.   The strip then lies at a 10-deg. angle with the horizontal.
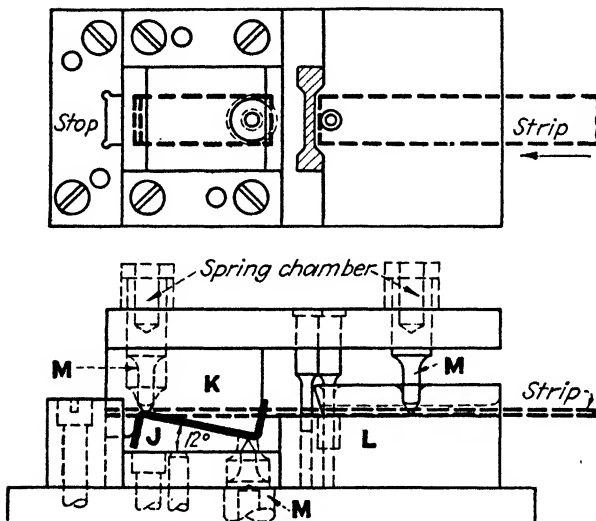
Fɪɢ. 137.—In contrast to Fig. 136, the cut blank is prevented from creeping by sharp
pointed pins actuated by compression springs.

When the ram descends, punch *F* severs the blank from the strip.
Continuing in descent, the punch forms the piece against block *G* and
over the right end of pivot block *E*.   Block *E* is supported at all
times in the bottom of its confining channel *H*.   When the ram
ascends, the work is ejected by the pull of the punch and the elevating
action of spring *I* on block *E*.

A die of different design for producing a similar piece is shown in
Fig. 137.   This tool uses a positive bending die block *J*.   The finished
work lies between the closed forming punch *K* and block *J*, at an angle
of 12 deg. with the horizontal.   The high point of bending die *J* is in
the same horizontal plane as the top surface of die block *L* to facilitate
feeding the strip.   When the punches ascend, the work slides off the
rear of the die, because the press is tilted.

When grinding the surfaces of cutting die blocks in tools of such designs, a like amount of metal is ground from the undersides of the forming blocks in order to maintain the tool members at the same heights.

A third die (Fig. 138) indicates the large range and simplicity of these piercing, cutting-off, and bending tools. The punch cuts off the strip with an inserted blade. Cutting occurs on the die-block edge at
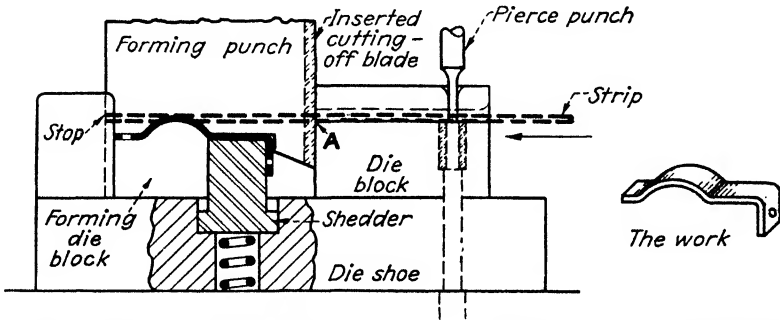
FIG. 138.—The inserted cutting-off blade can be lowered after grinding its angular edge Thus a constant length of forming punch is maintained.

A. Continuing in descent, the punch forms the arc in the work and simultaneously carries the blank down against the spring shedder, forms down the angle, and then registers the shedder in the die shoe at completion of the down stroke. The piece is now completely finished, as shown, between the punch and die. A spring shedder ejects the work when the ram ascends.

The strip is shown by heavy dashed lines over the forming die and across the punch. Its forward end is registered against a stop at the left. This is the first position of the strip before the ram descends.

CHAPTER XIV

DEVELOPING THE BLANK AND SCRAP STRIP

Using Formulas for Bends in Developing Blanks. Designing the Scrap Strip and Die, and Giving the Jig-boring Dimensions.

Importance of Laying Out the Scrap Strip First.

How Metals Bend.—If a blanking die has been ordered for a piece that is shown partially or completely formed on a print, a blank development must be made before starting the scrap-strip layout.

Developed lengths are computed from the *inside* dimensions of the bends; these dimensions locate the radial centers that describe the
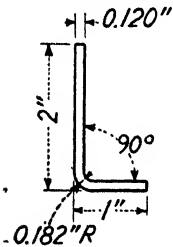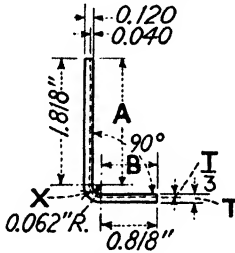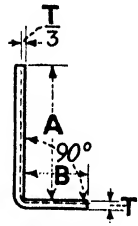
FIG. 139.   FIG. 140.   FIG. 141.
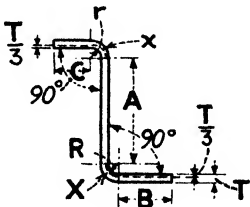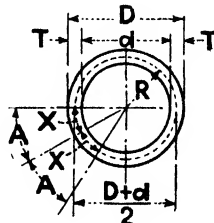
FIG. 142.   FIG. 143.

FIGS. 139 to 143.—The over-all length of a blank is the sum of the dimensions between the radii centers inside the bends, plus the lengths of the radial arcs.

bends. If the dimensions of the formed piece are given *outside* the bends, as in Fig. 139, then a preliminary sketch similar to Fig. 140 should be made from which the flat blank dimensions can be accurately computed. The dotted lines in the sketches represent the neutral bending lines.

If L is the required developed length of the flat sheet-metal blank for Fig. 140, then $L = A + B + X$, in which $X = [(T \div 3) + R] \times 1.5708$, for a 90-deg. bend. For any angular bend, $X = [(T \div 3)$

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+ R] × 0.01745N, in which N is the number of degrees in the angle. If the angle is given in degrees, minutes, and seconds of arc, N must be reduced to a whole number and decimal fraction before it can be used in the formula.

Practice has shown that for 90-deg. sharp-cornered bends (Fig. 141) the developed length is sufficiently accurate when calculated as
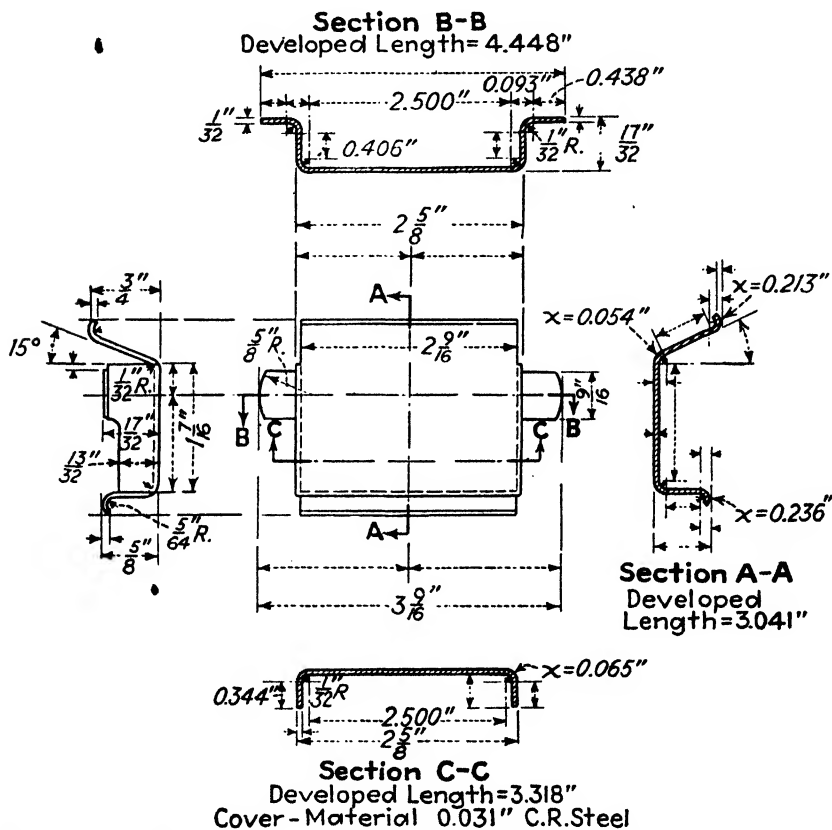
Fig. 144.—To assist in laying out a complicated blank, the part drawing is sectioned at important locations and the developed lengths of the sections are computed.

follows: $L = A + B + (T \div 3)$.   For two 90-deg. bends in opposite directions (Fig. 142), $L = A + B + C + X + x$, in which X or x $= [(T \div 3) + R] \times 1.5708$.   For circular tubes (Fig. 143), when R is greater than $2T$, the neutral bending line is central in the strip.   This is also adopted for all bends where R is greater than $2T$.   For the circular-arc length of a sector X (Fig. 143), $L = 0.01745 \times A \times R$.   In books of seven-place logarithms are tables giving the lengths of circular arcs for a radius of 1.   The tables give the arc lengths for each degree,

mınute, and second.   These tables save much time in computing blank developments.

The foregoing bending formulas, although based on the correct geometrical theory, give developed lengths slightly oversize because the metal stretches.   Recent tests seem to show that $T/5$ gives more accurate results for the position of the neutral bending line than $T/3$. This is particularly true for the commonly used U.S. gage sizes from No. 10 to No. 24.   Tables for bends are given in Chap. XXIII.

A Typical Blank Development.—Five views are shown in Fig. 144 of a sheet-steel cover for which blanking and forming dies are required.

For the blanking die, sections A-A, B-B, and C-C are drawn and the lengths developed.   In determining these lengths, the remaining dimensions follow easily.   *Inside* dimensions would be calculated for each of the three sections, and allowances made for the bends, as discussed in Figs. 140 to 142.   The sections can be sketched freehand to save time; but if the work were very small or otherwise complicated, it would be best to lay out the sections ten times the actual sizes.

By using the previously given bending formulas and methods, the developed lengths for the sections are 3.041, 4.448, and 3.318 in., respectively, as shown in the sectional views.   The completed blank development is given in Fig. 145. Developed lengths of the three sections are inserted as shown underlined, and the remaining flat dimensions can be taken directly or are obtained from the formed cover in Fig. 144.

Fig. 145.—By using the developed lengths of the three sections in Fig. 144, plus dimensions from the part, the blank layout is accurately determined.

The scrap strip is dimensioned as illustrated in Fig. 146.   This particular blank is to have four of its sides formed or bent.   Therefore, the blank is positioned at a suitable angle across the strip grain in order that all the bends can be made without danger of fractures.   Solution of several right-angled triangles, as shown, is a mathematical check that proves the practicability of this design. It shows that the scrap allowance between the blanks and the edges exceeds the material thickness.

Sharp bends, or those with approximately $\frac{1}{64}$ in. radius, can sometimes be made parallel with the stock grain and without noticeable

fractures, if the metal is very thin and soft. However, this practice is taking chances in favor of fractures; if the next consignment of material is less ductile, fractures or small checks are likely to appear outside the bends.

The more information one obtains about a tool the better he is prepared for a successful workout. The length of the cut edge of this blank is 15 in. By a previous formula, the blanking pressure required is 15 in. × 0.031 in. × 25 tons, or 11⅝ tons. A No. 2 press of 14 tons capacity is of sufficient strength to handle this job, but it is better to specify a No. 3 press of 22 tons capacity; the latter machine has a larger bed and a more suitable die space to accommodate the size of this
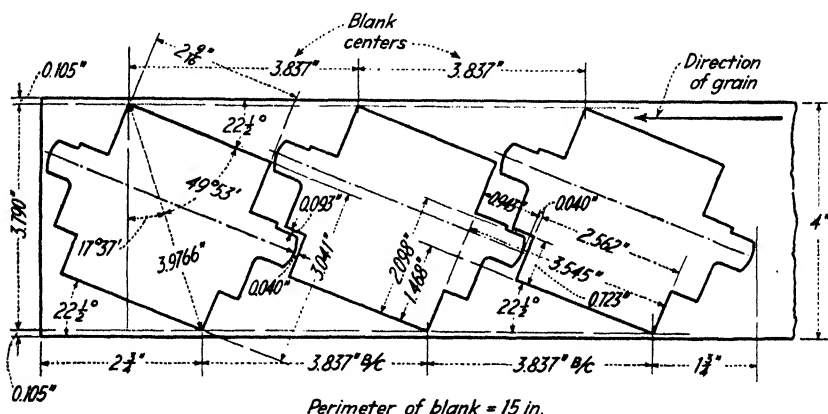
Fig. 146.—Method of laying out and computing the scrap strip. The 22½-deg. angular position of the blanks across the strip grain is ample protection against bending fractures in forming light-gage material.

particular press tool. The stripping pressure is 15 in. × 0.031 in. × 3,500, or 1,628 lb.

The number of full blanks contained in a strip 8 ft. long is as follows: [96 in. − (2¾ in. + 1¾ in.)] ÷ 3.837 in. + 1 = 24 blanks. The waste end length is 96 in. − [(3.837 in. × 23) + 2¾ in. + 1¾ in.], or 3¼ in. The waste end length also appears in the first formula, where (96 in. − 4.50 in.) ÷ 3.837 in. = 23.847, and 3.837 × 0.847 = 3¼ in.

The required area of strip for one blank is 3.837 in. × 4 in. = 15.348 sq. in. The weight of material necessary to make 1,000 blanks is as follows: 7.3 × 3.837 × 4 in. × 1.27 = 142¼ lb., in which 1.27 is the weight of the material in pounds per square foot, and 7.3 a constant which includes 5 per cent for waste ends.

Designing a Jig-boring Layout.—One of the several types of jig-boring layouts for the cover blank is presented in Fig. 147. The block has been turned 22½ deg. from normal to bring all the die dimensions

"straight" and to coincide with the straight dimensions on the blank in Fig. 145 and with those in Fig. 146. This maneuver avoids solving many triangular computations. The block is secured on the jig-boring machine in the position shown in the figure. In this way, most of the dimensions can be taken directly from the blank development in Fig. 145, and with the indicated additions, the dimensions can be incorporated in the layout.

The centers of all exterior radii must also be located. In Fig. 147 are two $\frac{1}{16}$-in. exterior radii. A $\frac{1}{16}$-in.-diameter hole is drilled at
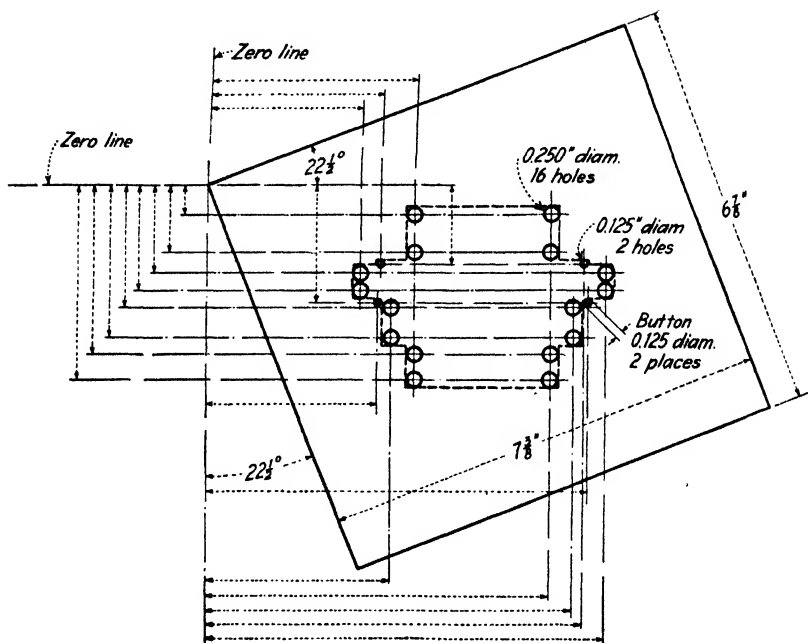
Fig. 147.—By securing the die block at a 22½-deg. position in the jig-boring machine, the layout will coincide with the blank development in Fig. 145. This saves much time that would otherwise be spent in many triangular computations.

these centers, and a hardened shoulder button 0.125 in. diameter is subsequently fitted in the holes and used as a filing templet for outlining these radii in the die. Stepped dimensions in the figure are purposely omitted. This layout is a very simple one. Some of them involve hundreds of dimensions, many of which must be determined trigonometrically.

Designing a Blanking Die.—Figure 148 represents a die of the "blank-through design"; it uses the die block shown in Fig. 147. This blanking die is one of the smaller types, sometimes referred to as a

"drop-through die" because the cut blanks drop through the die block, the die shoe, and the bolster plate and then out through the press bed.

This press tool is designed for use in a No. 3 nontilting gap press. The strip is passed by hand along the feed table, at the right, and under the channel stripper plate fastened on the die. The strip is halted at blanking centers, for tripping the press and cutting the blanks. Halting of the strip is controlled by the action of an automatic stop shown at the left. The mechanical operation of several types of automatic stops has been explained in Chap. X.
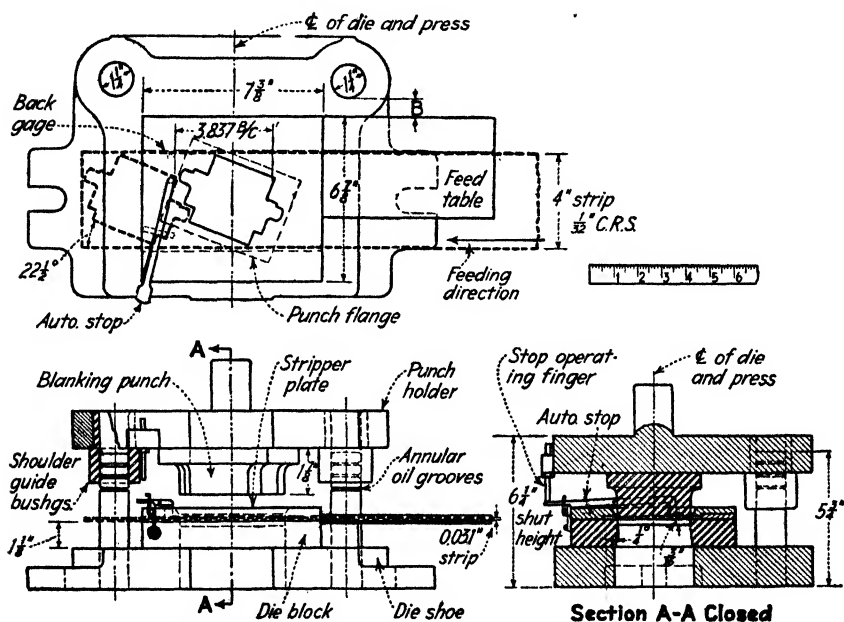
Fig. 148.—The die block in Fig. 147 assembled in the press tool. A drop-through die can be used for blanking on a gap press because the tonnage required is comparatively light.

To design the die block, draw and position the blank, full size, as it will appear in the die. Proportion the outlines of the block symmetrically around the blank to suit the blank size and hardening conditions. Block thickness depends upon the quantity production expected from the die. The thickness may vary from ⅝ in. for low requirements up to 1⅜ in. for medium-sized parts in continuous runs and high production. Faces of punches and die blocks must, of course, be ground for sharpening. Usually about 0.005 in. is ground off each time these members are sharpened. High-production blanking dies are often reduced by grindings until they fail by fracture.

The die may stand up even after being reduced to $\frac{1}{4}$ in. thickness by repeated grindings.

Selecting the Die Set.—The die set used in Fig. 148 is a standard type with two posts in the rear. Size of the die shoe should allow space around the die block for possible future additions, such as feeding devices and horizontal rollers designed to force the strip against the back gage. The spaces shown in the figure are about right. Space B is $\frac{5}{8}$ to $\frac{3}{4}$ in. for clearance between the guide posts and the nut on the grinding wheel, to facilitate grinding the die. Space B also provides clearance between the stripper plate and shouldered guide bushings. When the shut height of the tool is considerably reduced by grindings, the guide-bushing shoulders will interfere on the stripper plate, unless clearance space B is sufficient.

Checking Developed Blanks.—When precision results are wanted in sheet-metal bends, it is better to test several lengths of samples, measured before and after bending, and then follow average results.

If the designer has considerable experience in figuring bends, or the "checker" is one very familiar with such computations, further checking in the shop is unnecessary; otherwise the dimensions should be verified by a toolmaker before jig-boring the work. This is done by constructing the bending and forming dies first. These dies are then used in forming several samples of blanks made from the designer's dimensions. If the formed blanks coincide with the completed dimensions, the work is correct. One of the unused blanks is then converted into a die template, and a finger button attached. The template is used as a gage for testing the inside contours of the die opening when filing it to line. A template gage is unnecessary, however, unless the blank size is "very fussy," as they say in the shop, which means that high-precision work is required.

If the part is too complicated for accurate computation, the blank must be developed by a toolmaker. He constructs the necessary forming dies first and uses them in forming several handmade trial blanks. Starting with a blank that is obviously undersize, he follows with larger blanks until arriving at the correct size. Only three or four trial blanks are usually necessary. In such cases, the construction of the blanking die must wait until the correct blank size is determined. However, the blanking die can be designed and drawn, and the die material ordered, with a generous allowance made for the overall sizes of the punch and die blocks.

Necessity for Using a Straight-side Press.—The cover blank shown in Fig. 146 is a comparatively light cut. If it were three or four times larger and of $\frac{1}{8}$- or $\frac{3}{16}$-in. steel, the extra-high tonnage for this

cut would have required the use of a straight-side press. It would then be necessary to pass the strip through the press from front to rear, a much slower operation than the right to left movement used on gap presses. Blanking heavy strip, in straight-side presses, needs the attention of two pressmen. One man at the rear assists in guiding the strip and handling the heavy scrap. Another man in front of the press inserts and guides the strips under the stripper plate over the die.

Determining the Size of Die Blocks.—The sectional areas of a one-piece die block must be sufficiently large to resist hardening distortion. A generous section of metal should be provided between the nearest approach of the cutting-die edge and the block outline. This depends, of course, on the shape and area of the die opening; large openings require a proportionally greater sectional area around them. The section should never be less than the block thickness in small dies; it should be from $1\frac{1}{2}$ to twice the block thickness in larger dies. For the die block in Fig. 147, the surface width across the least section is $1\frac{1}{2}$ times its thickness.

Physical properties of the cutting steel also enter the die problem. They may govern the quality and working life of the tool, the production results, and frequency of grindings. For ordinary purposes, an oil-hardening steel is used in blanking dies. In high-grade dies for continuous runs, a special high-chrome steel is used in which the carbon content is about $1\frac{1}{2}$ per cent. This type of die steel is one of the air-hardening varieties. It shows a minimum of cracks and distortions even when hardening intricate shapes.

The subject of die steels for extraordinary conditions, under high production, varies so widely for different purposes among tool engineers and toolmakers that space forbids entering a discussion of it here. For unusual die work, it is best to consult sales representatives of steel, in order to obtain the right types.

Die steels are sometimes ordered of such sizes that the end grain stands vertical in finished cutting members. It is thought that this condition may prevent nicked edges in dies having close punch clearances and thus insure more enduring edges. The finished sizes of die parts are specified $\frac{1}{8}$ in. under the rough sizes furnished by the mills. This procedure saves material in shaping the blocks; it allows $\frac{1}{16}$ in. for removing the "scale" on rough stock.

Tool-steel Tubing.—This material is made in many sizes up to 14 in. diameter and 2 in. wall thickness. It can be purchased in cut-off pieces. Such pieces save the time and expense of making expensive forgings.

Improvements in Diemaking Practice.—Die- and tool-shaping methods have advanced toward greater speed and accuracy in recent years. Not so long ago it required several days to saw and file a hand-made blank, to scribe it on a block, and to drill long lines of holes close together, preparatory to breaking out the center and hand filing the die opening in a bench vise. With the advent of jig-boring equipment, three-dimension profiling machines, and, more recently, band-sawing and filing contours on the same machine, together with the grinders that finish the interiors of dies with a vertical "pencil wheel," the die-maker's art has become a mathematical certainty.

SCRAP-STRIP DESIGNING

Introduction.—A correct scrap strip is the first step in designing a blanking die. To a great extent, the layout of the scrap strip determines the general design and dimensions of the press tool. If the blank is not to be formed or bent, the grain direction in the strip usually can be ignored. Grain in metal strip follows the direction of the mill rolling and usually is parallel with the strip length. Blanks to be formed should be positioned in the strip so that none of the bends will be less than 30 deg. across the grain. If the bends are sharp cornered and positioned less than 30 deg. or approach a parallel direction with the grain, such bends may fracture while being formed to 90 deg., if the material exceeds $\frac{1}{16}$ in. thick.

Sharp-cornered bends should be avoided if possible, unless the material is less than $\frac{1}{16}$ in. thick and of high ductility. Investigation may show that there is no reason for having sharp-cornered bends in the piece and that a change can be made to radial arc bends and fractures thus avoided. For steel blanks that require sharp-cornered bends in several directions, it may be possible to use open-hearth sheet. This material is a ductile deep-drawing steel; it has a dull and rough appearance but no perceptible grain direction.

Burr Side Up.—The "burr side" of a blank is the punch side. In bending operations it is advisable to place the blank in the die with its burr side up. In this position the forming punch in descent flattens the burrs. This avoids wearing burr grooves in the dies, which may easily occur if the blank is placed burr side down in the forming tools.

Methods Used for Scrap-strip Layout.—In laying out the scrap strip, cut three cardboard outlines of the blank. Place them in symmetrical horizontal rotation with their extreme upper and lower edges in line, as shown by the blank in Fig. 149. A neck of metal, equal to the material thickness, should separate the nearest cuts between the blanks, and the same allowance should be provided between the

extreme end cuts and the strip edges. These allowances in thin metal strips, under $\frac{1}{32}$ in. in thicknesses, should be twice the material thickness, or even more for very thin stock.

When strips are passed through the die twice, for cutting a double row of blanks, the lateral separation between the cuts should be increased, because the strip will lengthen and the blank openings "creep ahead" when cutting the second row. Under these conditions the punch will finally cut into the openings of the first row. This fault may force the punch out of its true course and cause it to contact the
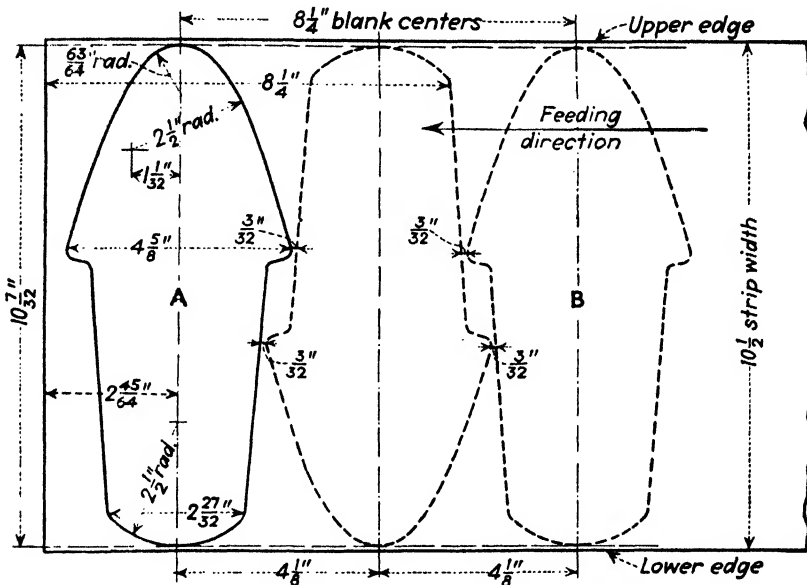
Fig. 149.—The highest material economy is determined by positioning three cardboard outlines of the blank *A* in symmetrical rotation, and by comparing the unit area of material required for one blank with the unit areas found by rearranging the blanks in several other positions. The unit area is found by multiplying the distance between blank centers by the proposed width of the strip.

die edge, resulting in nicked or sheared cutting edges. Even though the cutting edges are not damaged, the blanks so made are imperfect; they lose part of their outline and become scrap.

In the course of trying the paper blanks in several proposed positions in the strip, the most economical layout for saving material is found by multiplying the distance between blank centers by the proposed width of the strip and comparing the areas. This multiplication gives the approximate area for one blank. The least area is the one most economical of material, but there may be several reasons why it cannot be adopted. (1) It may have the wrong grain direction across

the blank for successful forming; (2) shearing a multiple of strips of the proposed width from commercial sheets may be wasteful; or (3) the blank centers may be too long for rapid die production, and in this last case the final waste end of the strip is probably too large.

Layouts in which the strip must be passed through the die twice should be avoided if possible, but for saving of material such layouts are often necessary. It is not unusual to design the die for cutting two or more blanks at each press stroke; thus a multiple of blanks are made in one pass of the strip. Blanking dies of this type are high-speed producers but are too expensive to build except for large-quantity production.

The blank in Fig. 149 is wider just above its center than at its opposite end. Obviously, for this shape the most economical layout would be the one shown, where the strip is passed through the die twice. Most blanks that have this typical shape are generally positioned in the strip for double-row blanking, as shown. Sometimes the blanks are positioned in a bias direction across the sheet to obtain a narrower strip, and by thus overlapping the blank contours the result is a lower unit area.

In the illustration, the die cuts the first blank at position A; the strip is then advanced $8\frac{1}{4}$ in. toward the left and over the die, where blank B is cut. After cutting all the blanks on the $8\frac{1}{4}$-in. centers, through the first row in the strip, the sheet is then turned opposite side up, and the second row is cut from the spaces that remain between the first blanked openings. The lower edge of the sheet, as shown in the cut, then becomes the upper edge; and, as in blanking the first row, the upper edge rides against a hardened back guide strip provided under the stripper plate and across the upper part of the die block. After all the blanks in the sheet have been cut, the center distances between the openings are $4\frac{1}{8}$ in., or half the blank centers in the tool. The method of stopping the sheet for cutting the first blank in the second row is illustrated in Fig. 125.

It is not always the case in running a double row of blanks, however, that the center distance between all the blanks is one-half the blanking centers. The exception is when the blanks have unsymmetrical areas on opposite sides of the vertical centerline of the blank, as shown in Fig. 150. Dimensions X and Y are unequal, but their sum, of course, must always equal C, or the blanking-center distances. In double-row strips, special finger stops for gaging the first cuts and the proper location of the stop for rotation cuts are sometimes rather complicated to design. These are illustrated and described in Chap. XII, Figs. 124, 125.

How Many Blanks per Strip?—A commonly used method for find-
ing the number of blanks contained in the length of a strip is to reduce
the length to inches and divide by the distance, in inches, between the
blanking centers.   Figure 151 shows an example wherein 10.125 in.
divided by 2 in. gives five blanks per strip.   In this particular case the
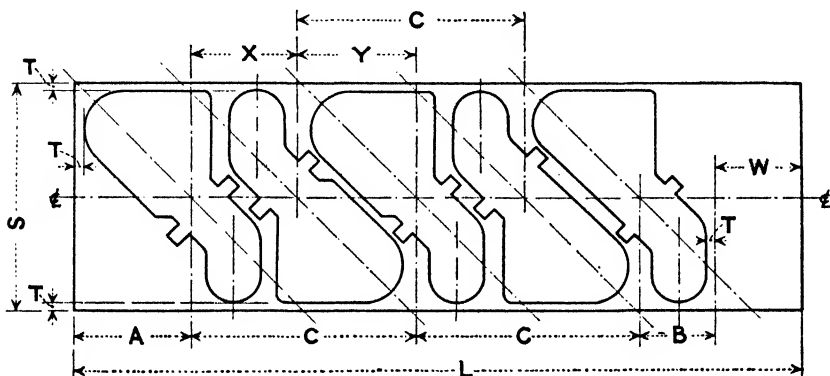
Fig. 150.—When blanks are unsymmetrical about the center line, dimensions *X* and *Y*
are unequal in double rows of blanks.

method gives the correct result, but it is incorrect in so many other
cases that it should not be used in any case.   This computation is
suitable only for small blanks and symmetrically shaped pieces such as
washers or where considerable waste or the shortage of a blank at the
final end of the strip can be ignored.
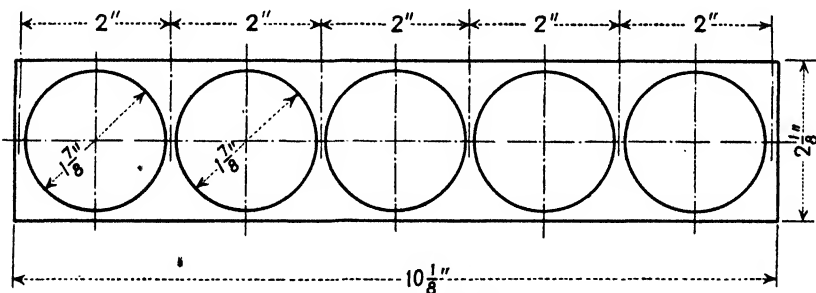
Fig. 151.—The number of symmetrical blanks contained in a given length of strip
is the length divided by the distance between blanking centers, but this method is
unreliable when the blanks are not symmetrical.

For unsymmetrically shaped blanks which have right- and left-
hand projections that overlap and for blanks positioned at an angle
across the sheet, the correct number of blanks per strip cannot be
accurately computed by the foregoing method.   It is not recommended
for computing the number of large blanks in short strips or for blanks

from expensive materials in which a slight alteration between blanking centers might easily include or lose another piece in the given length of strip.

To know the amount of waste that remains after cutting the last blank in a strip is even more important in the case of short strips than in long ones. For very long strips and for coil stock, the waste end usually can be ignored; but in short strips this waste is repeated oftener and must be known and considered in the cost of the material used.

Calculations for finding the number of blanks per strip are simple. In Fig. 152 there is a single row of blanks in a strip lettered for using
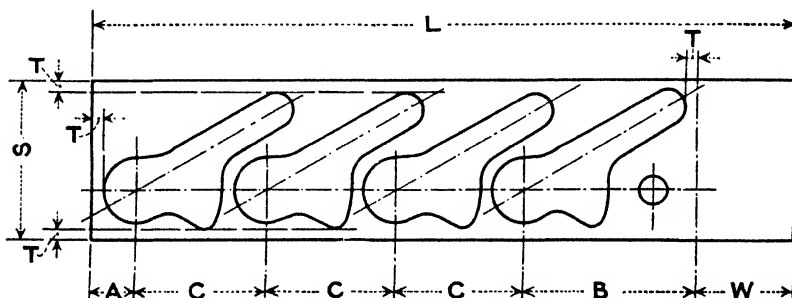
Fig. 152.—A single row of blanks lettered to suit the formulas given for accurately computing the number of blanks per strip. For double rows of blanks, use Fig. 150.

the following formulas in which all the dimensions are in inches. First, it will be observed that the sum of

$A + B + W + (C \times \text{its multiple}) = L$, or the total length of the strip.

where A = distance from front end of strip to first blank center.

$\quad\quad B$ = distance from last blank center to furthermost cut + T.

$\quad\quad C$ = center distance between blanks.

$\quad\quad L$ = length of strip.

$\quad\quad N$ = number of blanks per strip.

$\quad\quad S$ = strip width.

$\quad\quad T$ = thickness of strip.

$\quad\quad W$ = waste end length.

$$N = \frac{L - (A + B)}{C} + 1.$$

In using $\dfrac{L - (A + B)}{C}$, take the whole number and drop the fraction.

$$W = L - [C(N - 1) + A + B]$$
$$\text{Area of one blank} = \frac{S(L - W)}{N}.$$

For a double row of blanks, as shown in Fig. 150,

$$N = \frac{L - (A + B)}{0.5C} + 1.$$
$$W = L - [0.5C(N - 1) + A + B].$$
$$\text{Area of one blank} = \frac{S(L - W)}{N}.$$

The length of the waste end W must be less than enough to make another blank.

For Circular Blanks.—In the fabrication of round washers, spool heads, small gear blanks, slugs, and rollers from sheet materials, the
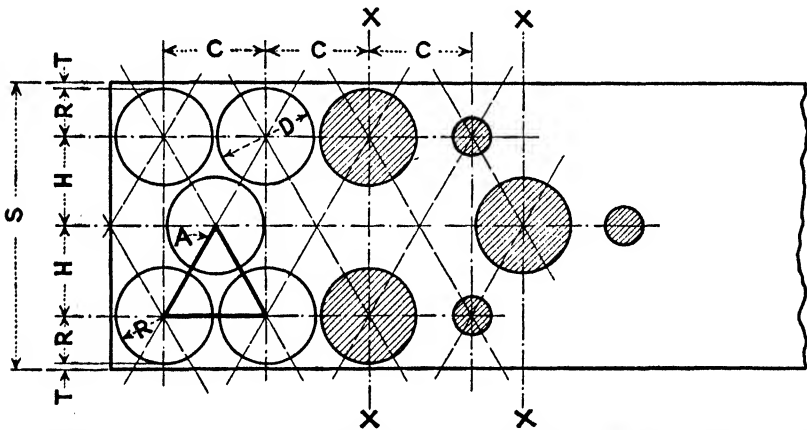
FIG. 153.—The most economical material layout for round blanks, and positions of the die openings for piercing and blanking of symmetrically shaped parts.

dies are designed for multiple blanking if the orders are sufficiently large to warrant it. The die openings for three blanks per press stroke are arranged in the design shown by the section-lined openings in Fig. 153. For any reasonable number of blanks per stroke, the design can be increased by adding more die openings above or below, on lines X-X.

Triangle A is equilateral, and each of its sides is equal to C, which is also the distance between blank centers. $C = D + T$, in which D is the blank diameter and T the material thickness. The altitude H of triangle A is equal to $C \times \cos 30$ deg., or $0.86603C$. The width of strip S equals $2H + D + 2T$.

For a single row of circular blanks, the amount of scrap is about 34 per cent. For a double row of blanks, the scrap falls to 27 per cent; and for a triple row, to 23 per cent. For more rows than three, the decrease in scrap is very small, and the cost of tools, upkeep, and handling of the strip increases out of proportion to the saving. Scrap strips for hexagonal nut blanks are similarly laid out unless a "no-scrap nut die" is the design wanted.

No-scrap Nut Dies.—Figure 154 represents the commonly used design for piercing, blanking, and cutting off hexagonal nut blanks, $\frac{5}{16}$ in. across flats, for quantity production. This type of die is termed a no-scrap nut die. The material waste is practically negligible; only the round slugs and the two narrow borders are scrap.

The die openings are shown by section lining. Pilots in the blanking punch faces, in descent on line X, engage in the holes pierced in the first station and thus register the advanced strip just before blanking. Four nuts are cut off on the die edge Y-Y, at each advance of the strip; and with the five blanks that are cut through the die, nine pieces are made per press stroke.

The 0.2706-in. vertical dimensions are determined by multiplying the distance between blank centers, 0.3125 in., by the cosine of 30 deg.,

FIG. 154.—A no-scrap layout for piercing, blanking, and cutting off hexagonal blanks for machine-screw sizes of nuts.

or 0.86603. Large quantities of blanked nuts, for machine-screw sizes, are usually made of brass, and this layout proves very economical of material. A 6-in. length of strip is left in the tool, after running an order, so that finger stops are unnecessary in starting the next run.

Importance of Economical Scrap Strips.—Using the most economical scrap layout for expensive materials cannot be overstressed. This is particularly true where large outputs are involved. For example: A small phosphor-bronze spring clip, $\frac{3}{16}$ by $1\frac{1}{16}$ in., of 0.020 in. gage, required 125,000 blanks daily, 2 blanks per press stroke. It was found that a previous layout used $1\frac{1}{4}$ lb. of stock per 1,000 blanks. These conditions seemed to appear good at first thought. However, another arrangement of the blanks in the strip saved $\frac{1}{4}$ lb. of stock per 1,000

blanks. The new layout saved only 10 cents per 1,000 blanks, but this amounted to $12.50 daily, or $3,837 annually.

How Many Pounds of Stock per 1,000 Blanks?—Several methods are available for computing the weight of material required per 1,000 blanks. In the following formulas all dimensions are in inches.

$C =$ center distance between blanks.

$M =$ material weight per cubic inch.

$S =$ strip width.

$T =$ thickness of strip.

$P =$ pounds weight of the material per square foot.

$X =$ weight of material required per 1,000 blanks.

The area required for one blank $= C \times S$.

$$X = 6.944 \times C \times S \times P \qquad \text{or,} \qquad X = \frac{C \times S \times P}{0.144}.$$

Each of these formulas gives the *exact* number of pounds of material for 1,000 blanks, but it is customary to add 5 per cent to this result for waste ends of the strip. This addition is necessary in all cases unless the material is coil stock.

The following formula also gives the number of pounds of material for 1,000 blanks and includes 5 per cent for waste. This is the usual formula used for short strips but not for coiled stock.

$$X = 7.3 \times C \times S \times P \qquad \text{or,} \qquad X = \frac{C \times S \times P}{0.137}.$$

Another formula is

$$X = C \times S \times T \times M \times 1,000.$$

This is a simpler formula because in the final multiplication by 1,000 the decimal point can simply be "set over" three numbers to the right. The usual 5 per cent for waste should also be added to the result. However, this formula is not so accurate as the others given, because disagreement for the values of M is found in tables given by different authorities. This formula is used mostly for estimating the approximate cost of materials per 1,000 blanks. In all cases, when C and S are intended for blanking multiple rows, the final result obtained by these formulas must be divided by the multiple to obtain the weight for 1,000 blanks.

SCRAP STRIPS FOR MULTI-SLIDE MACHINES

Introduction.—In progressive dies, the scrap strip determines the tool layout to an even greater extent than in other types of dies. Pro-

gressive dies are used in all types of presses but mostly in multi-slide machines and gap presses.   A plan drawing of the strip shows the die operations to be performed at each successive station and suggests the manner of doing them.   If the piece includes a drawing operation, or form and bends, it is advisable to draw plan views of the strip, the die plan, and a front elevation below the plan.   These views show where the die blocks, stripper, pads, punches, perforators, pilots, push-off pins, and cutoff and forming are necessary.

Typical Strip for Multi-slide Machine.—Multi-slide machines and progressive dies involve additional principles in scrap-strip layout. General dimensions for a piece to be pierced, notched to outline, formed, and cupped on a multi-slide machine are shown in Fig. 155. Two forming designs are shown, and both are made from the same blank.   The piece is a double-end "jack spring" made from 0.010 in. gage tempered phosphor-bronze strip.

To form a blank in two or more shapes, on this machine, the forming punches and dies are removed, after running one shape, and others of different form are substituted.   The forming punch and die holders are mounted in separate slides and are operated by cams which advance and allow the forming members to dwell at position *A* (Fig. 156).   The slides are adjustable in all directions and are independent of the piercing and trimming die holders.   Die openings are shown by the section lining.   The strip is fed from left to right.

Stock strip is unrolled from a horizontal coil, on a reel, by the pull of a "hitch-feed" arranged in the machine.   The strip passes "edge up" through straightening rolls and then through the feeding jaws. Then it passes under a positively attached channel stripper plate which covers a vertical die block.   A pilot punch engages in the center hole of the work to insure accurate alignment of the strip.   The center hole is pierced at the first station, as shown.   The piece is cut off in the forming operation at *A*, on line *X-X;* this line is the right-hand edge of the die block.   The cutting-off blade is adjustable and is mounted on one of the forming slides.

An endless variety of small parts and intricate forming operations can be fabricated in these machines, and the output lies between 125 and 300 finished pieces per minute, according to the size and difficulty of the work.

In these types of progressive layouts be sure to take the following precautions: (1) Separate all cutting edges as far apart as possible; (2) provide minimum thickness of die blocks; (3) perforate the holes for subsequent piloting in the first station, if possible, and have the pilots enter in the following station; (4) consider the possibility of

Fig. 156.—The scrap strip for this part shows the sequence of die operations in a typical layout for multi-slide machines. Notice the generous sections of steel between cutting edges.

Fig. 155.—Intricate parts involving piercing, notching, severing, and forming of two distinct pieces from one blank, are made in multi-slide machines.

separating the die block into sections for easier working out of the die openings, remembering that very small die openings are difficult to file through; (5) provide backing-up heels on all trimming punches; (6) position blank in regard to the strip grain for forming the part without fractured bends; (7) provide push-off pins where necessary; they are sometimes needed in the die block where embossing is done. Push-off pins, in progressive dies, are usually necessary after forming operations.

Standardizing on a Few Sheet-gage Sizes.—Sheet-metal gage sizes can be confined to a few numbers. Select standard sizes that the supplier usually has in stock. Some shops have reduced gage sizes to six. The sizes are selected to cover the average run of work. When heavier gage sizes are wanted for greater strength, the pieces can be designed of thinner material and "ribbed" to increase stiffness. This avoids introducing other new gage sizes.

Using only a few gage sizes often saves changing an old forming die or making new forming and drawing dies, because in these types of tools the material thickness is the governing factor, and a previously made die can sometimes be used for making a new part, if the material gages are the same.

Collaboration between Apparatus Engineers and Tool Engineers.—
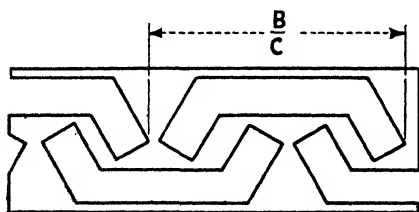
Fig. 157.—The usual layout for straight blanks with hooked ends is very wasteful of material.

This cooperation is desirable because it frequently saves material and tool expense. Cases occur in which tool engineers discover that if a certain piece could be slightly changed in design, a far more economical scrap strip would be possible or a stronger die, without expensive inserts, would result. Foreign manufacturers, whose materials are more expensive than ours, lay great stress on this point.

Some large concerns assign a cooperating tool engineer to the apparatus-designing staff. An example of the good results obtained is shown in Figs. 157 to 159, inclusive. The usual scrap layout for straight pieces with "hooked ends" is seen in the double-row scrap (Fig. 157). At first thought this conventional layout would pass unquestioned. However, it is very wasteful of material. It utilizes only 62 per cent of the strip.

If another blank, of different shape, can be made in the same die along with the original piece, which is sometimes done for economy, and the strip then designed as in Fig. 158, only 64 per cent of the strip

is used. However, the tool engineer assigned, discovered that the only constant dimensions in this piece were A, B, and C. Therefore, by redesigning the piece, as in Fig. 159, a new strip design became possible which utilized nearly 100 per cent of the material, as shown in Fig. 160.
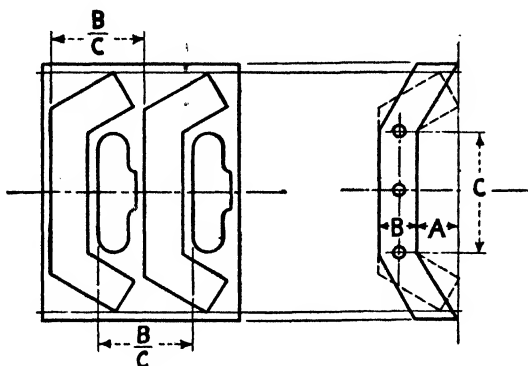
FIG. 158.—The blank in FIG. 157, shown in another position to include a smaller different blank, is also wasteful.

FIG. 159.—The blank in Figs. 157 and 158 redesigned for economy of material.

Another case of saving material is illustrated in Figs. 161 to 163, inclusive. The original strip is shown in Fig. 161. An experienced glance at this layout suggests waste; 4 sq. in. is used in making one blank. By alternating the blanks in a double row, as shown in Fig. 162, only $3\frac{7}{16}$ sq. in. was used for each blank. This appeared to be good economy until further investigation revealed that about one-third of each piece could
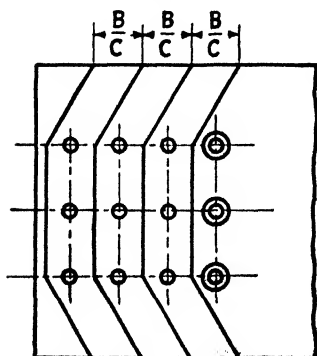
FIG. 160.—A scrap strip in which the waste is negligible for the blank shown in Fig. 159.
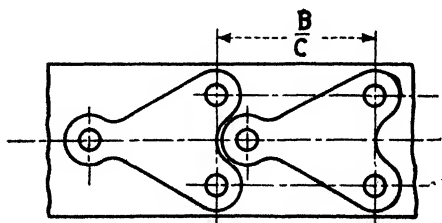
FIG. 161.—This layout is wasteful. Four square inches are used for each blank.

be cut from the piece ahead, as sketched in Fig. 163. In this design, the utility of the part is unchanged, and the area for one blank is reduced to only $2\frac{3}{4}$ sq. in., or a saving of 32 per cent, compared with the original layout.

A familiar layout are the U-shaped blanks in Figs. 164 and 165. This part cannot be run in a double row as shown in Fig. 157, because dimension *A* is less than *D*. The scrap design in Fig. 164 uses only
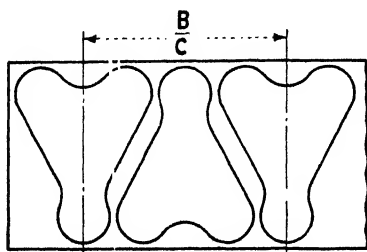
FIG. 162.—Another layout of the blank in Fig. 161, in which only $3\frac{7}{16}$ sq. in. are used per blank, but even this layout is wasteful.
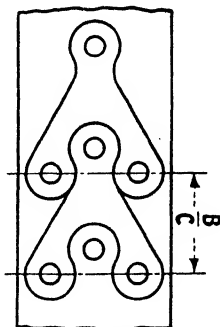
FIG. 163.—This layout of the blank in Fig. 161 is a result obtained by changing the piece slightly. It saves 32 per cent of the material, compared with the first layout.
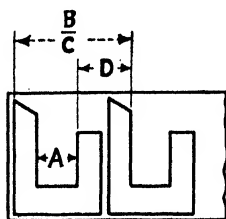
FIG. 164.—This layout utilizes only 38 per cent of the material strip.
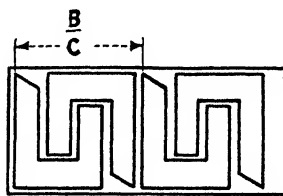
FIG. 165.—This layout of the piece in Fig. 164 uses over 70 per cent of the material strip.
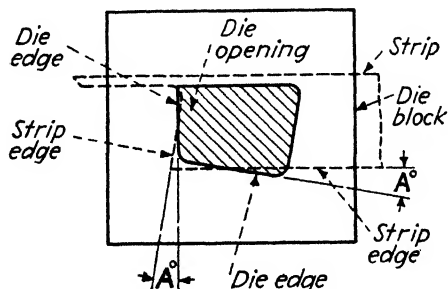
FIG. 166.—A condition to be avoided are long cross cuts in the strip at acute angles with die edges.

38 per cent of the strip; but if the blanks are arranged as in Fig. 165, 70 per cent of the strip is used. In the latter figure, the second row is run by turning the strip end for end.

In automobile-body fabrication, many small stampings are cut from the scrap taken from window openings. If manufacturers neglected to follow this economical practice, competition with others who did would not be possible.

In Fig. 166 is a cutting condition that is encountered quite frequently in blanking and shearing cuts. If angle *A*, on the piece to be cut, is less than about 10 deg. with the die edge, both the punch and the die will wear rapidly at the point of crossing and require too many grindings. The remedy is to change the angle or redesign the piece to avoid the trouble.

CHAPTER XV

SHAVING, BURNISHING, BROACHING, AND TRIMMING

Shaving and Burnishing Dies Produce Smooth Square Edges on Portions or the Entire Contours of Blanks

Broaching Dies with Effective Work Clamps Produce Cuts That Would Otherwise Require Several Difficult Milling Operations

Trimming Dies for Forgings, Castings, and Round and Rectangular Shells. The Bliss and Brehm Methods for Trimming Irregular Shells

Introduction.—Edges of cut blanks are never perfectly square with the faces of the piece. This condition is unavoidable in plain blanking dies. For blanks in ordinary use this discrepancy is allowable. It is caused by the punch-clearance gap; and unfortunately as blank thicknesses increase, greater punch clearances are necessary, and consequently the blank edges become less square.

All blanks have rough fractured edges arising from the break that follows punch penetration. This fault is particularly true in thick blanks. There are cases, however, where this condition is undesirable. For example, rough edges, burrs, and the round corner on blank edges are objectionable on pawls, ratchet wheels, and gears, because for satisfactory performance these pieces must have smooth, square, and sharp edges at working surfaces.

Smooth square edges, as just described, are produced by shaving the blanks by putting them through a second-operation die. If the round edge must be entirely removed, the blanks should have milling cuts taken across the edges of the working surfaces. The cuts must be deep enough to remove the rounded edge, and sufficient metal must be added on the blank for that purpose.

The amount of metal removed in shaving dies is one-tenth of the blank thickness. Clearly this 10 per cent shaved off should exceed the punch-clearance percentage that caused the rough and out-of-square edges. The extra 10 per cent of metal is added on the blank size at shaving points.

There are several tool designs and methods for handling the work in shaving dies. Blanks that require a shaved finish all around the

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edges are pushed through a die by a punch having the same contour as the die. The punch clearance is practically a negligible amount; it is not more than $1\frac{1}{2}$ per cent of the material thickness, over all, and the die clearance is little or none. Guide posts of substantial diameters should be incorporated in the die set.

Principles in the Design of Shaving Dies.—The blanks are centralized over the die either within a "nest of pins" or between a pair of centralizing hand clamps shown in Fig. 167. The shaved pieces fall out under the die and press each time another blank is pushed in by the punch above. Pilot pins, projecting from the punch, engage holes previously pierced in the blank. When the punch descends, the pins
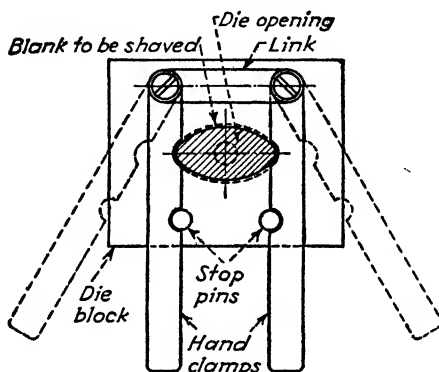
FIG. 167.—If there are no pierced holes in the blank for piloting when shaving, hand clamps are used to centralize the blank over the shaving die. The size variation of blanks is not great enough to prevent using this method of centralization.

guide the work centrally into the die. If the blank has no pierced holes, then suitable holes are added for piloting and guiding the blank when shaving it. If adding holes is objectionable, then the hand clamps shown in the sketch are substituted for centralizing the blanks.

An improvement that adds several advantages can be made in the design of this shaving die. A close-fitted shedder is placed within the die opening and operated by the conventional spring compression bumper underneath the die shoe. With this design (Fig. 168) the finished pieces are free of burrs and dents which may occur when they fall out beneath the press. In the design just described, the finished work is delivered by the shedder *above* the die face after the shaving is done.

With the shaving die mounted on the punch holder, and the punch attached under it on the die shoe, we have a convenient design for a die that shaves a blank all around. After the blank has been shaved into the die, it is ejected by a "knockout" shedder which has an

attached vertical rod. The shedder is a close fit within the die, and its method of operation is the same as described for inverted blanking dies.
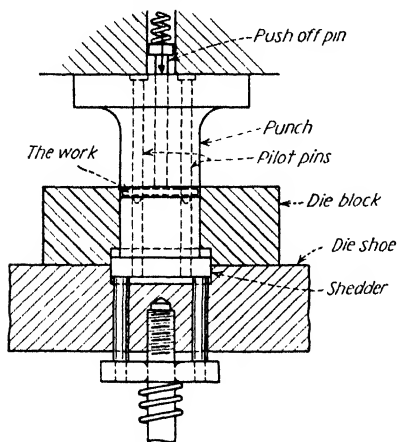
FIG. 168.—A spring shedder in the die block delivers the shaved pieces above the die face. This avoids the burred or nicked edges on the pieces that occur when they are allowed to fall out beneath the press.

Using this design practically solves the chip problem. Chips cause considerable trouble on the die surfaces of shaving dies of other designs. In this design, the chips fall below the punch and on the die shoe and clear the punch face for taking the next blank. The blanks are placed over pilot pins fixed in the punch, which insures equalized shaving. When the ram descends, the die edges do the cutting against the edges of the punch. The shaved blank is carried up within the die when the ram ascends and is ejected as previously described.

Shaving Disconnected Edges. Portions of a blanked edge can be shaved in a die similar to that shown in Fig. 169. This is the usual press-tool design for shaving an edge at one or more places. It is the
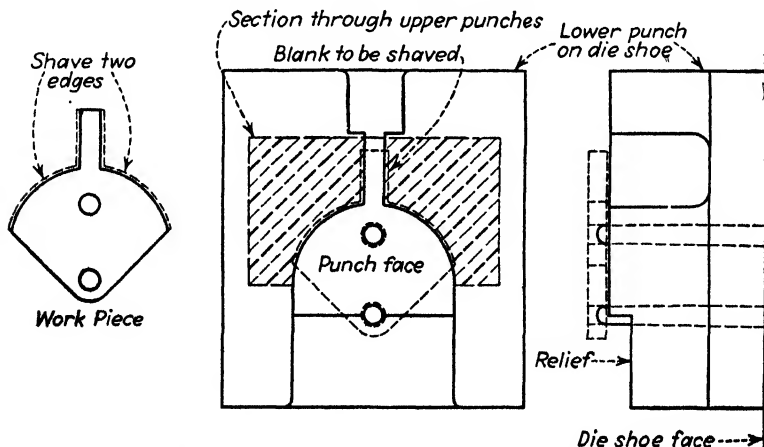
FIG. 169.—Two opposite edges are shaved by using inverted tools, in which the upper die is really just another pair of punches.

"inverted type" of press tool where the die is above, but which is really just another pair of punches, as shown in the sketch. A "knockout

shedder" is unnecessary for ejecting the finished pieces from the die, but this is true only when none of the cuts is diametrically opposite or nearly so. Holes in the blank are placed over the registering pins shown in the punch face. A strong spring pad, within the upper punches, holds the work flat on the lower punch face when the ram descends for shaving.

When there are no holes in the blank and when undesirable to add them, locating strips are arranged on the lower punch face, opposite the cuts, to position the blanks. A recess or relief in the lower punch
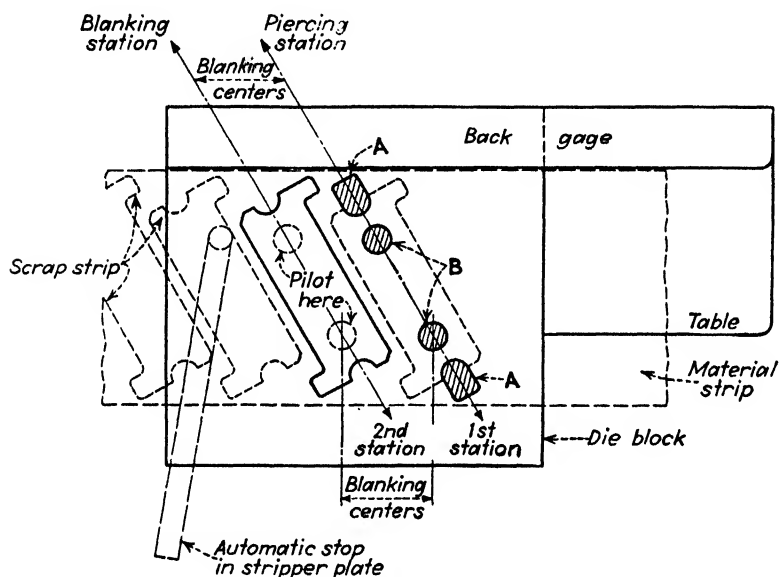
FIG. 170.—Shaving is combined with blanking in this two-station tool. Success depends on having adequate pilot holes *B*.

face is provided at convenient locations to allow the pieces to be "flipped off" the pins with a hand pick after shaving.

Shaving and Blanking Combined.—A shaved edge is cut to specified sizes at one or more places on a blank by incorporating the operation in a two-station piercing and blanking die. This principle is shown in Fig. 170. At the first station, two elongated holes are perforated at *A*. These holes provide that one-tenth of the material thickness remains on the blank at places to be shaved. When the pierced holes in the strip are advanced into the second station and the ram descends, the blank is cut as usual, and at the same time the previously prepared edges are shaved by the blanking punch. This idea saves the cost of a separate shaving tool.

The success of this method depends entirely on having one or more pilot holes in the blank from which to register the work by the entrance of substantial pilot pins which protrude from the face of the blanking punch. In the sketch, pilot holes are pierced in the first station at *B*. The diameters of pilot holes should not be much less than the material thickness for registry of the strip when blanking. Larger holes than these are preferable if possible to have them.

Selecting the die set depends on the size of the blank, its thickness, and whether or not close tolerances are expected in the work. A large thick blank may be shaved in a four-post or staggered-post set; a smaller piece is done in a die set having rear posts only or in a center-post set. If the piece to be shaved is steel and has a thick edge several inches in length, it is good practice to use slight shearing angles on the
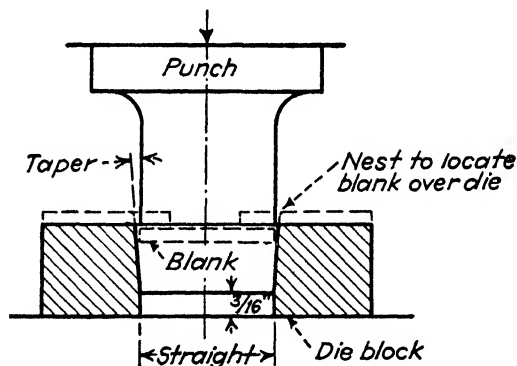
FIG. 171.—Forcing a shaved blank through a highly polished tapered die will burnish its edges and improve the functioning of the piece in precision mechanisms.

die face. For shaving thick interior edges, the punch face carries the shearing angles.

Small precision parts, such as moving parts in clocks, watches, and adding machines, are shaved in an arched-barrel subpress die. For larger precision parts, a pillar subpress die set is used.

Burnishing Dies.—These dies are closely related to shaving dies because shaved edges are never perfectly smooth without burnishing. If a shaved edge is examined under a good lens, it will be found to resemble the cross lines on the edge of a file. These parallel lines represent minute irregularities in the cutting edges of the shaving die.

Shaved edges are usually satisfactory for pieces in ordinary use; but for small working parts in precision mechanisms, a burnishing operation is necessary to obtain smooth polished edges. A burnishing die is illustrated in Fig. 171.

In a burnishing tool the die opening is slightly tapered inward from the top surface and downward through the die block. The tapered surface ends ³⁄₁₆ in. from the bottom of the block, and for the remaining distance the sides of the opening are vertical. The interior of the die is finished smoothly; and after hardening, it is then highly polished. When the blank is forced through the die by the punch behind it, the edges of the piece are compressed; and in crowding through the slightly tapered opening, the edges take the same degree of polish as provided in the die.

Burnishing Round Holes.—The interior of pierced holes can be burnished to size by forcing commercial steel balls through them with a punch. The balls drop into a tray under the die and roll out in front of the press and are used again. Punch diameters are made 0.005 in. less than the hole sizes, and stripping the work from punches is unnecessary. This operation may be satisfactory for small consignments but is too slow for regular production. For burnishing holes rapidly, highly polished bullet-nosed punch points are used. The work is stripped off under an open-side, positively attached stripper plate or, for light stripping, by a spring pad surrounding the punches.

The stripping is sometimes done by a "knock-off plate" which surrounds the punches and is operated by an attached knockout rod carried up through the punch shank. The work clings to the punches after they enter the work and is carried up when the ram ascends. Stripping occurs when the free end of the knockout rod contacts the crossbar through the head of the press. The method of stripping depends upon the conditions involved.

PRESS BROACHING

Introduction.—In general, broaching dies are used for cutting shapes in light and medium-heavy parts; but there is no reason why they cannot be employed in heavy operations, given the correct punch speed and the necessary travel of the press slide. Deep broaching operations, in quantity production and for parts too large for power presses, are fabricated in broaching machines in which a long broaching cutter is ordinarily pulled through the work.

Broaching dies are particularly useful in operations on thick blanks, for internal cuts through forgings and castings, and for external cuts in either the sides or at the ends of commercial sections. Internal broaching is used for enlarging round holes or for changing them to other shapes.

In broaching dies, the work must be rigidly clamped in opposition to the cut, and all the working members of the die, especially the

broaching punches, must be of sturdy construction. The broaches should be well supported and guided in order to resist excessive wear and breakage. The die set should have precision-fitted guide posts of comparatively large diameters; a "staggered-post" type of die set equipped for broaching in a straight-side press is the ideal setup.

Broaching cuts are governed by the same restrictions as are found in all other machine-cutting operations, namely, to attain the maximum speed of the cutting tool, in feet per minute, without its showing excessive wear or failure; the disposal of chips; use of proper lubrication; the effect of certain tooth shapes; and the maximum feeding distance into the work that the teeth can safely take per cut.

For certain external cuts, broaching is considerably faster and less expensive than milling. For example, it is a simple operation to broach several straddle cuts in a single-operation die, on the opposite edges of work and at given distances from the ends of long pieces. To mill the same cuts, several operations would be necessary unless an expensive and complicated fixture were used.

An example of internal broaching is in cutting a keyway along a finished hole through a hub. The broach, in descent, "pilots" through the hole in the hub, and the teeth do not begin to cut until the pilot end has fully entered a fixed guide bushing beneath the work. A clearance slot is provided within the wall of the bushing coincident with the line of travel of the broach.

For external cuts, broaches are designed with comparatively heavy backing heels. The heels are supported and guided on three sides by long slots cut in guiding blocks which are rigidly attached to the surface of the die or shoe. Guiding slots are lined with hardened, ground, and lapped plates to insure long wear. The guides are attached opposite the cuts. Guiding should start above the cut and continue down to the surface of the die shoe and beyond if necessary. Only the cutting edge of the broach is exposed, plus a small clearance, which together provide sufficient depth to suit the operation.

The cutting principle governing the operation of broaching punches, the tooth shape, and the chip clearance is closely related to that of formed milling cutters. The travel of a broaching punch should not exceed 40 ft. per minute in ferrous metals. An emulsion cutting compound is used for steel forgings and cast iron to obtain free cuts and smooth finishes. Some grades of steel forgings may require a lubricant of animal oil for heavy cuts. Brass can be cut up to 80 ft. per minute, or higher, for light operations of regular contours. Cutting speeds employed in hydraulically driven broaching machines seldom exceed 40 ft. per minute.

These data indicate that a power press, which has been speeded for ordinary piercing and blanking dies, has a slide travel that is about right for broaching. A press slide that runs at 120 strokes per minute and is driven by a 1½-in. crank throw has an average descent of 30 ft. per minute. For presses that run at higher speeds it is advisable to reduce the number of strokes per minute for heavy broaching operations.

Designing the Teeth.—The usual shapes for broaching teeth are shown enlarged in Fig. 172. The pitch P, or the distance from tooth to tooth, is determined by the formula $0.35\sqrt{C}$, in which C is the length of the cut. However, it is best to decrease the constant 0.35 to 0.20 when cutting distances are less than ½ in., so that two or more teeth will be cutting at the same time.

The "land" L, which is about ⅕ P, is slightly "backed off" as indicated by angle B; this angle may vary from zero to ¼ deg. The pitch can be decreased to suit unusually hard or difficult work or for abnormally long and wide cuts. The tooth angle T, which is normally 30 deg., is sometimes decreased to avoid weakening the cross section in very small broaches.

Fillet R, at the root of the teeth, is made as large as chip space will permit. Chip clearance may be increased by using an arc connection as shown at D, instead of a straight-line connection between the teeth. The last three or four teeth at the top are straight in line for accurately finishing the cut. A rake angle H, of 5 to 7 deg., can be specified in all the teeth; this design favors curling the chip and tends to decrease the pressure required to operate the broach.

The feed from tooth to tooth is determined by the cutting resistance of the work material the same as it is for cuts in other power-driven machines. It depends largely on the hardness or toughness of the material

Fig. 172. In a press broaching tool, it is best to make the first three or four teeth closer than pitch P, so that they act as leaders.

and the quality of finish desired. The feed is controlled by the acuteness of angle A; this angle can be slightly altered, if necessary, after the broach has been hardened in changing the angle by grinding. Tooth opening O is approximately equal to depth of the tooth/tan T, and the feed per tooth is equal to tan $A \times P$.

Broaching Keyways in Hubs.—Figure 173 shows construction principles of a die for broaching a keyway. The punch diameter is an easy sliding fit through the center hole which was previously bored in

the hub; it also slides through the guide bushing. A longitudinal slot, shown in the punch, seats the broach blade.

When the ram descends, the blade broaches the keyway and continues in descent through a clearance slot in the guide bushing. A stripper fork over the work, omitted for clarity, prevents the work from ascending with the punch and permits the broach to withdraw. The die set is the "staggered-post" design.
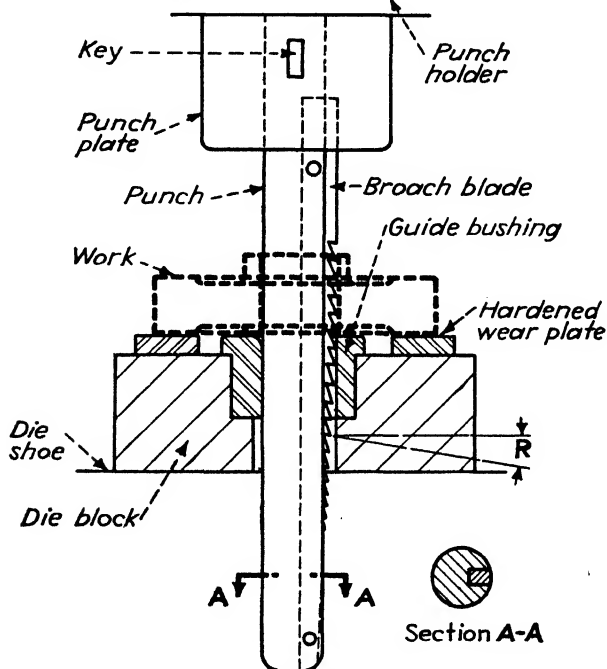
Fig. 173.—In broach-cutting slots, such as keyways through a hub, the teeth are usually undercut as shown by angle *R*. This undercut, or *front rake*, is ordinarily made between 3 to 7 deg; it is designed to curl the chip, produce a smoother cut, and to reduce pressure on the broach.

Scope of Die Broaching.—For broaching square and rectangular holes, the usual design of the broaching cutter is seen in Fig. 174. The cutting teeth are slanted across the face of the tool at an angle of about 5 deg. The angular slant of the teeth causes them to shear-cut the chip. This feature gives a smoother finish than straight-across teeth give; it also reduces pressure on the teeth. Shearing angles are in opposite directions on opposite sides of the broach, which balances the cut and leads the tool straight. Broaching punches of this type are usually pushed entirely through the work and die holder and then returned by hand for making the next cut.

It has been said that the operation of die broaching is simply a series of multiple shaving punches of increasing sizes passing through the work. This is an interesting comparison, inasmuch as it directs attention to the surprising similarity in different kinds of cutting operations.

The variety of shapes that can be broached are limited only by the skill of the designer and toolmaker in producing a tool blank of the proper length, taper, and cross section and in providing it with the most efficient number and shapes of teeth and lastly by the ingenuity of the tool hardener. A broach that has warped in hardening can sometimes be straightened while the temper is being drawn.

Broaches are commonly used for these shapes: round, oval, square, rectangular, regular or irregular polygons, and combinations of these shapes. Keyways, splines, and small internal gears are well-known examples of broaching. Internal helical grooves can also be broached by causing the broach to revolve while following through the lead of a long spiral. Broaching is a "straightaway" cut; it is a cut easily controlled by the length of the broach, by the depth of the feed per tooth, and by the number and shapes of teeth. It is possible to broach a large variety of external contours for small slots such as half-hexagonal and U-sections; this can be done on a production basis more rapidly in a die than by milling with a profiling cutter. Pads and bosses on castings and

Fig. 174.—Teeth on a broach for enlarging a square or rectangular hole should be slanted in opposite directions on opposite sides to provide a shear cut and to avoid side thrust.

forgings can also be broach finished on a high-production basis. Special broaching machines are commercially built for this purpose.

A fixture similar to one for milling is made to hold the parts and to support the surfaces to be broached, near the cuts. In modern broaching machines, the cutters are attached on vertical holders, operated hydraulically. Many small parts of army rifles, such as trigger guards and triggers, rifle bolts, and the front locking lug, are broached, internally or externally as required, at production rates of 200 to 800 pieces per hour. Automotive steering knuckles are also broached on several surfaces simultaneously. Broaching is rapidly replacing

milling in light manufactured parts.   It is much faster than milling and
makes smooth cuts without leaving revolution marks.   A vertical
broaching machine is simply another type of metalworking press.

External Broaching.—Foregoing references to the sturdy design
necessary in all parts of broaching dies are exemplified in Fig. 175,
which shows a job of external broaching.   The work to be broached is
a short hexagonal section of cold-drawn steel, $\frac{1}{2}$ in. across flats, and
is "nested" in the die block B, endwise between gage pins C.   The
operation consists of one external broaching cut.   Additional opposite
cuts, or end cuts, could all be made at the same time if necessary.   For
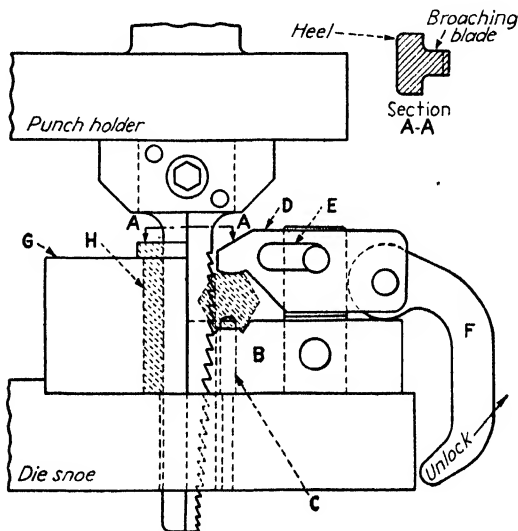
Fig. 175.—Clamp D prevents the work from turning with the cut and is clamped and
released by a one-hand movement of handle F.

an external cut on one side of round stock, great clamping pressure is
essential; otherwise the piece will revolve with the downstroke of the
broach.   In such cases a pair of clamping jaws are necessary, and
the moving jaw should equalize when closing upon the work.   A clear-
ance slot for the cutter is, of course, necessary down through the sta-
tionary jaw.   In opposite cuts where the cutting pressures balance on
the work, heavy clamping is not so vital.

As shown, clamp D prevents the work from turning with the cut.
The clamping point is located close to the operation.   The clamp is
unlocked and pulled back through slot E, for removing finished pieces
and to reload the tool.   Cam handle F is used to release or to lock the
clamp, and this can be done, either way, by a one-hand movement.

A simple device may be installed, in tools of this character, to eject the finished pieces automatically. A spring plunger is arranged to bear against one end of the piece and with a positive stop pin at the opposite end. The work is "snapped" between them when loading. After the cutting operation, the clamp is pulled away; and by simply
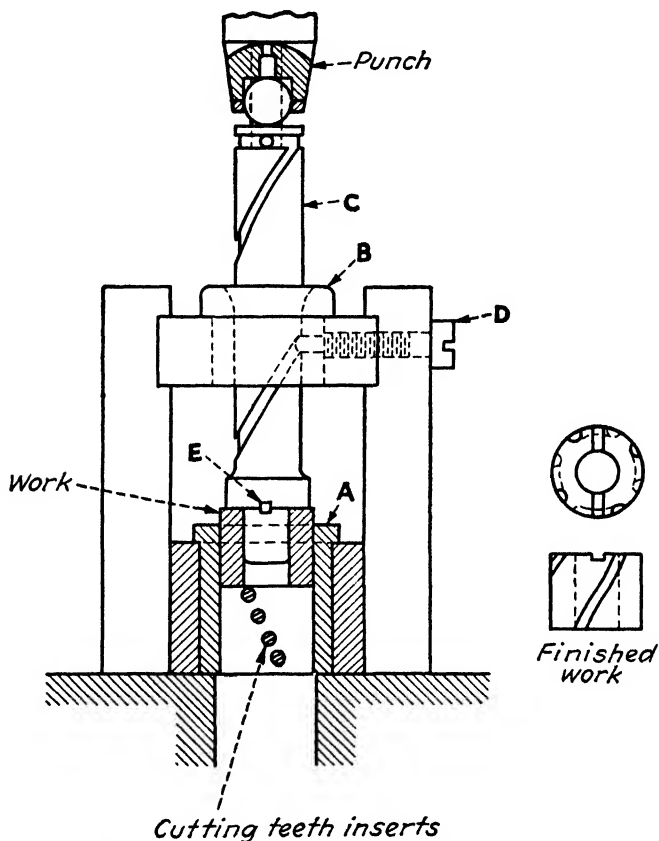
Fig. 176.—Plunger *C* moves downward in a spiral path and its key *E* engages a slot in the work to drive it in a similar path, while inserted broaching teeth in bushing *A* cut spiral grooves in the outer surface of the work.

depressing a lever that protrudes in front of the die, an ejector pin is caused to contact under the work near the stop pin. This action lifts the work above the stop, and the spring plunger instantly throws the piece endwise out of the die.

The tapered cutting edge on the broaching blade is exaggerated to show it clearly. Block *G*, with its wear casing *H*, "backs up" the heel around the broach. The blade and heel are one piece of cutting steel

as shown in section A-A.   The T-section of the broach strengthens the
blade greatly; it prevents distortion in heat-treating and hardening,
provides a larger guiding surface, and maintains cutting precision and
long wear.   The die set used is one of the long, narrow "staggered-
post" types.

External Spiral Grooves.—A principle often used for die broaching
exterior spiral grooves on the surfaces of bushings, or on any short
lengths of cylindrical work, is shown in Fig. 176.   The broaching teeth
are inserted through holes within bushing A.   Bushing B is a guide for
the spiral-grooved plunger C.   The spiral leads in A and C correspond.
A point on screw D is engaged in the spiral groove and causes the
plunger to revolve when it is advanced by the punch.   The punch has
a retained steel ball which bears on the end of the plunger and reduces
the pressure friction between them in descent.

The work is placed within bushing A when the plunger and punch
are up.   In descent the punch causes the key E, at the end of the
plunger, to engage in a previously broached slot across the work.
This arrangement causes the work to revolve with C in descent, while
cutting through A, until the work is pushed out finished beneath the
press.

The plunger ascends with the punch because of an attachment
shown between them in the groove around the top of C.   This is a fast
operation for cutting oil grooves in duplicate parts.

TRIMMING CIRCULAR AND RECTANGULAR SHELLS AND FLAT EDGES

Introduction.—Waved edges around the open-end side walls of
drawn shells and the overflow flange or fin on hot- and cold-swaged
parts must be trimmed for the removal of irregular outlines.   In brass,
zinc, and aluminum castings and around the contours of drop-forged
pieces a surplus of metal may purposely be allowed for a final trimming
operation.

Flash Removal.—Most cold-swaged parts must be trimmed.
When the body of the part is swaged to size, the surplus metal in the
blank overflows between the punch and die and forms an attached fin
surrounding the piece.   It is the fin that must be trimmed to complete
the work.   The fin may not be entirely removed in trimming, but its
outline may be trimmed to suit a flanged contour in the final design
of the part.

Irregular edges around the tops of drawn shells are either pinched
off at the time of drawing or cut off in a subsequent trimming opera-
tion.   For small shells the trimming is sometimes done in a hand fix-
ture, and for larger shells in a trimming lathe; however, for quantity

production a commercial die known as a "Brehm trimmer" can be used.

When the open ends of drawn shells terminate in an annular rim or flange, the outer edge is also irregular until trimmed to size. If the drawn shell and rim are comparatively small, as produced in multiple-plunger eyelet machines or in small progressive dies, the rim is trimmed in the final station, and the finished shell is then pushed through the die by the trimming punch.

"Pinch-off" Trimming in Drawing Dies.—In progressive dies and eyelet machines, drawn shells with straight sides can be
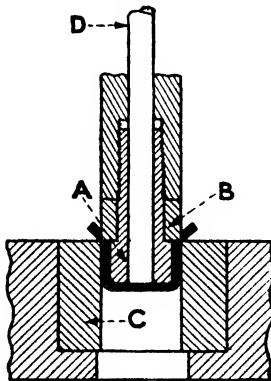
Fig. 177.
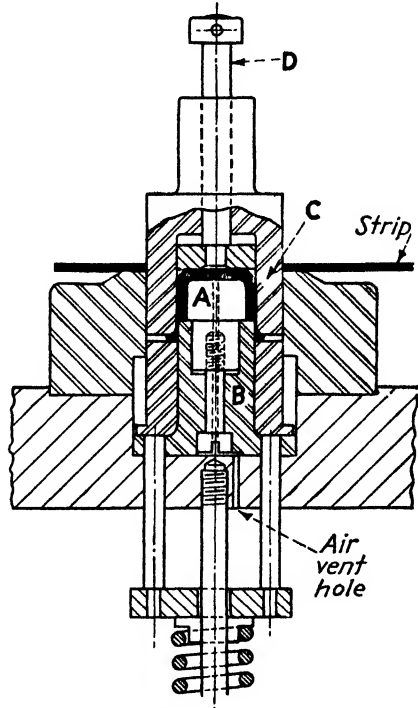
Fig. 178.

Fig. 177.—A cutting ring *B* fits snugly into the die opening and is set at the correct height from the punch face, in order to pinch off the upper edge of the drawn shell to the required depth.

Fig. 178.—The principle illustrated in Fig. 177 is applied to a compound die; an air inlet is added to prevent a vacuum under the shell when being raised from punch *A*.

trimmed by pinching off the surplus ends. This process produces an edge slightly rounded and somewhat thinned, but the shell is usually satisfactory for ordinary uses. Figures 177 and 178 illustrate the design of drawing dies used for pinching off the tops of shells.

Figure 177 represents the conventional die used for drawing cylindrical shells in eyelet machines. It shows the final pinch-off station for sizing the shell diameter and trimming surplus metal from the top by pinching it off. The drawing punch *A* carries the shouldered cut-

ting ring B, which can be adjusted to length after grinding. The height from underneath the ring to the end face of the drawing punch equals the finished depth of the shell. The cutting-ring diameter provides for only the thickness of the shell wall around the drawing punch. External diameters of the cutting ring and shell correspond to the internal diameter of the drawing die C.

When the punch descends, it draws the shell into the die to a position where the cutting ring closes the die opening. The cutting-ring edge is then forced through the interior side wall of the shell and completes the cut as it enters the die. The punch, continuing in descent, delivers the shell through the die. Knockout rod D strips the work from the punch when the die is used in an ordinary single-action press with a spring shedder pad under the shell.

It is necessary to expand the pinch-trimming idea only slightly to understand that other shapes than a straight-around trim can be made. Like the Bliss and Brehm trimmers, shallow notches or irregular edges can be cut around the top edges of shells. If the shouldered cutting edge on the punch is laterally waved or notched, a similar cut is transferred into the trimmed edge of the shell. The punch must be adjusted to push the shell into the die far enough to finish the highest cut.

Figure 178 shows a method for trimming off shell ends in a single-action combination blanking and drawing die. The stripper plate has been purposely omitted for clarity. Similar tool members have been lettered the same as those in Fig. 177, because the trimming action is the same in both.

A hole is drilled through the punch, with an outlet in the die shoe, to admit air into the shell. This avoids creating a vacuum within the finished shell when it is being lifted from the punch and carried up within the die during the ram ascent and final ejection. Such construction is necessary because the success of a positive knockout depends entirely upon the certainty that the finished work will cling to the moving member of the die when it ascends.

Positive Knockouts.—Generally speaking, positive knockouts are used when the cutwork clings so tightly in the dies, or around punches, that spring-pad stripping would be impractical. They are used in dies where a positively attached stripper plate would interfere in placing the work piece for an operation. When the blanks are $\frac{5}{64}$ in. thick and up, a positive knockout is a more reliable work ejector than using springs. To eject heavy work with springs requires great compression, and heavy springs working against the ram descent is an unfavorable condition which should be avoided.

A positive knockout is a great convenience if conditions favor its use. The work can be carried up with the ram ascent and then ejected clear of the dies. It is a quick and reliable method for automatically disposing of finished pieces. In using spring strippers there is always a chance of ejection failure, and the unobservant operator may continue feeding the tool which results in broken punches or dies, a fracture in the press frame, or distorting the crankshaft.

Selection of a suitable stripper depends largely on the type of the die and the shape of the work. For example, positive-knockout stripping is impractical in high-speed progressive dies because of the speed and because the stations may not be situated near enough to the punch

Front Elevation   Side Elevation
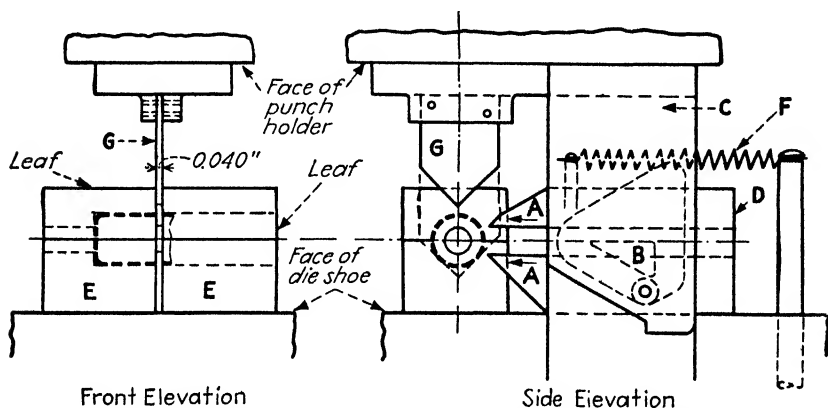
Fɪɢ. 179.—Edges of drawn shells or tubing can be cut off squarely and without burrs by utilizing balanced cuts produced by two cutting blades *A*.

shank to operate a knockout rod through it. High-speed dies use light-gage metals which do not usually require positive ejectors.

Selecting Strippers.—Automotive-body shops have adopted the following formula for stripping pressures determined from tension-testing machines. The formula is also of value in determining stripping pressures in small dies. By using it, the strength and number of stripper springs can be ascertained, also the size and number of screws necessary for holding down positively attached stripper plates. In this formula

Fɪɢ. 180.—Necks *H* in the shells are left by the cutting blades *A* but are severed by the descent of punch *G*.

P = pressure required for stripping in pounds,
L = length of the cut edge work in inches,
and T = thickness of the material strip in inches; then

$$P = 3,500 \times L \times T.$$

Balanced-cut Trimming.—A noteworthy tool design for trimming the ends of drawn shells and for cutting off lengths of tubing with smooth square edges and without burrs is sketched in Fig. 179. The work is shown in Fig. 180. This shearing die is designed for handling only light-gage nonferrous metals. The tool operates on the "balanced-cut" principle, as shown by the double cutter blades *A*. When the ram descends, these blades are advanced into the work by the descent of the hypotenuse in the right-angled triangle *B*. The hypotenuse is one side of a slot cut in the surface of cam plate *C*. The hypotenuse along this slot contacts the roller shown attached on slide *D* which carries the blades.

The work is held during the cutting interval by the two body and leaf blocks *E*. The leaves are opened to remove the trimmed shell and to place another shell for trimming and are then locked with a cam not shown. Although it appears at first that the sharp points on the blades cut from outside the shell, this is not exactly true. The points on the blades first shear an oblique cut through the arc of the shell wall, and the remainder of the cut is from inside the shell and outward.

Advantages of Balanced Cut.—In using this principle, no appreciable burrs can be formed on the inside edge of the shell, and the close-fitted blades in the slot between the holding blocks prevent burrs forming on the outside edges. In other words, this is an inside cut performed by outside cutters. An arbor is an unnecessary support within the shell, because the direction of all the cuts is away from the inside wall.

After the cam plate has descended to where the roller passes the acute angle in triangular slot *B*, the blades have finished the cut, and tension spring *F* immediately withdraws the holder and blades just before the

Fig. 181.—Forged parts, as shown at the left, are placed in a trimming die for the removal of flash or fin. The surplus material trimmed off is shown at the right.

vertical cutter *G* descends to finish the cuts previously made. The ram, continuing in descent, forces the angular cutting blade *G* through the 0.040-in. slot which shears out the two small remaining necks *H*. In ascent, the roller on slide *D* follows through the vertical slot along the short side of triangle *B*. The roller is shown in its normal position in the sketch, with the ram up and ready to trim the next

shell. This idea is sometimes utilized in a bench-fixture design, in which compound hand levers operate the cutting blades.

Trimming Flash from Forgings.—Figure 181 shows a drop-forged connecting rod and the scrap frame which has been cut off in a trimming die set up in a straight-side press.

Trimming large forgings may be done before the metal begins to cool, or in another operation after it cools. It all depends on the question of output, shop practice, and available equipment. Small forg-
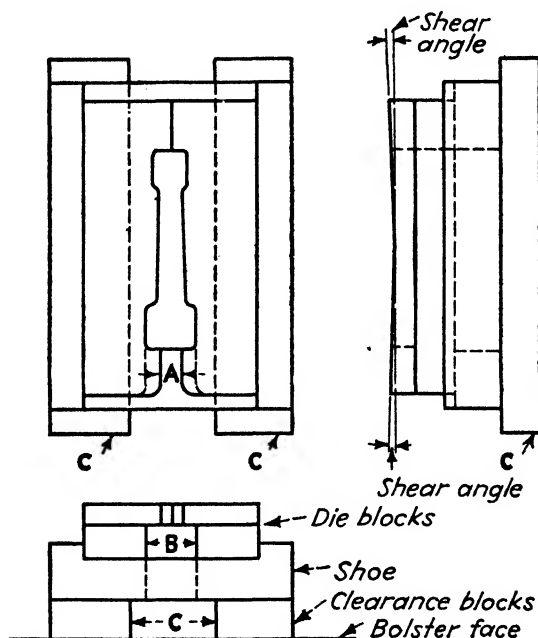
FIG. 182.—Open type of flash-trimming die for forged parts. The closed type is of similar design without opening *A*. Clearance blocks *C* are extended for clamping purposes.

ings are always trimmed cold in ordinary gap-type presses. For constant production in which hot forgings are passed from one "strike" to the next, hot trimming is obviously more efficient.

The tools for trimming forgings are simple blanking dies and usually of rather crude designs and cheap construction (Fig. 182). The cutting dies are made in halves, and in some of them the blanking contour is left open in front to clear the grip tongs or the end of the forged bar which is used as a handle for passing the part into other dies for reforging after trimming. The work is pushed through the die and into clearance space *B*, from where it is removed.

Figure 182 represents the open-end type of flash-trimming dies. The closed-end type is the same design without opening A.   In the latter type the trimmed piece falls through the die and shoe and between clearance blocks C, on the bolster plate.   The punch contour
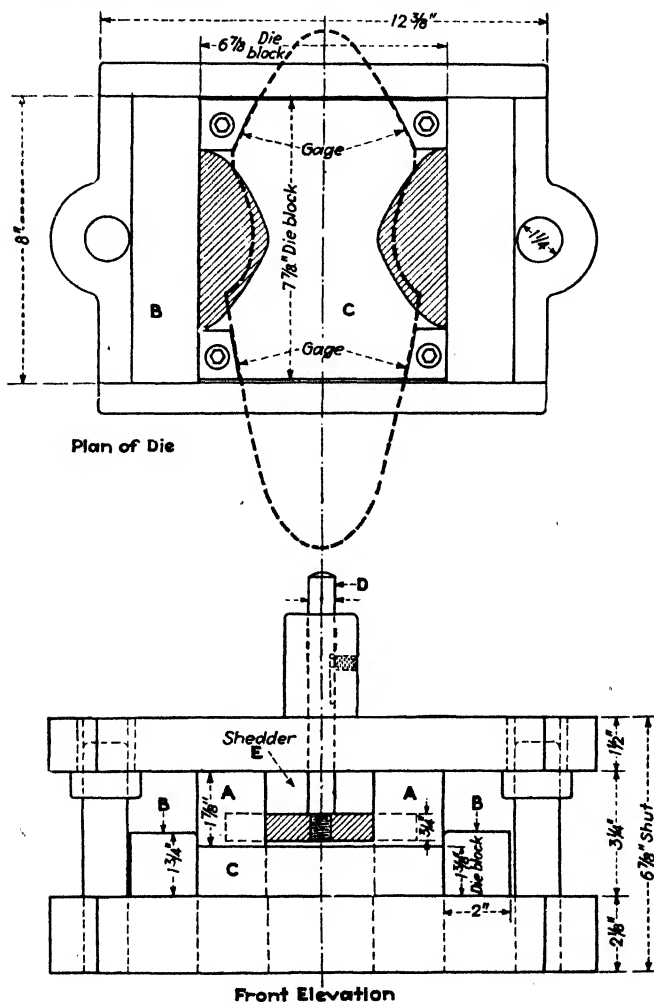
Fig. 183.—It is cheaper and quicker to build a trimming die for reshaping a given blank to suit a new drawing operation than to build a new blanking die.

roughly follows that of the die but is $\frac{1}{16}$ in. smaller to clear the scrap frame.   The die-face shearing angles cut the flash from the ends of the piece toward the center.

Trimming Blanks to Make Other Blanks.—Whenever blanks can be trimmed to make other blanks, the time and expense of making

another blanking die are saved. The idea is exemplified by Fig. 183. The original blank outline, shown dotted over the die block, is in position to be trimmed when the punch descends. In this way two styles of blanks are made available for different shapes of drawn work. The larger blank is trimmed to make a smaller one.

In this case, instead of designing the trimming punches *A* with heels, which prevent nicked cutting edges (in a "bite-in cut" through heavy sheet), the backup heels are separate pieces fastened on the surface of the die shoe at *B*. This leaves the faces of the trimming punches free of heel obstructions which may interfere with grinding.
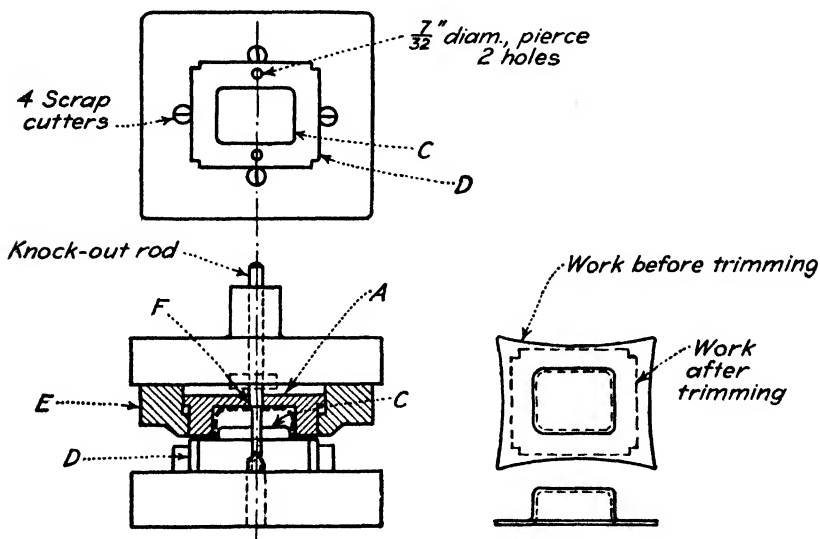
FIG. 184.—A drawn cover is accurately positioned over the pilot plate *C* for trimming and notching the flange. When the ram ascends, the cover is ejected by the operation of a knockout rod attached to pad *A*.

After the downstroke the blank has been "cut in" between the two punches. It is then carried up, when the punch ascends, until the upper end of the positive knockout rod contacts a bar through the head of the press. This suddenly forces down shedder plate *E* attached to the rod, and ejects the blank.

Flat-edge Trimming.—Methods of trimming circular shells by the "pinch-off" and "balanced-cut" principles were described under Figs. 177 to 180. Other principles must be adopted for flat-edge trimming of flanges on rectangularly drawn covers and in the special tooling devised for shells of any cross section.

Tools for trimming the rough-drawn flange on a rectangular cover are shown in Fig. 184. This view shows the cover before and after

trimming as well as the front elevation and plan views of the die.   The material is $\frac{3}{64}$-in. deep-drawing steel, and the piece is a coil cover.

In this operation, it was necessary to design an inverted tool in which the die block E is mounted on the punch holder above the trimming punch D on the die shoe.   The reason for this was to dispose of the scrap easily by cutting it into four pieces.

Knockout pad A, attached to its rod, is recessed to clear the body of the rectangularly drawn shell on the work, and its face bears directly on the flange surrounding the piece.   By these conditions, pad A ejects the work without distorting the flange.

The work is placed on the face of the trimming punch D and is accurately located by fitting the shell over the rectangular pilot plate C.   When the ram descends, the edges of the flange are trimmed, and its four corners are notched as shown by the dashed lines in the sketch of the work.   The notches are necessary for the subsequent operation of forming down wings on four sides of the flange.   Face of punch D is ground $\frac{1}{2}$ deg. horizontally from its center for a shearing cut.
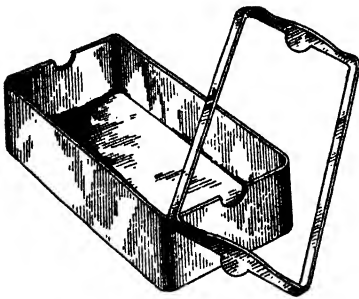
Fig. 185.—Illustrating a square-edged trimmed and notched sample of a drawn receptacle, showing the scrap frame removed.

In addition to trimming, two $\frac{7}{32}$-in. holes are pierced by punches F. Four sharp-edged scrap-cutting chisels are located as shown, one on each side of the punch.   These cutters divide the rectangular scrap skeleton into four equal pieces and make it easy to remove them.

The work having been sheared into the die, it remains there until the upstroke is nearly completed; at which time the work is ejected by the positive knockout rod with its attached pad, as indicated in the illustration.   The front elevation is shown at nearly its closed height. The style of die set used is the center-post type.

A feeding chute can be arranged to slide the untrimmed pieces into the die and to locate them over the pilot.   This would avoid injuring the operator's hand by placing work in the danger zone between the dies.

Square-edged Trimming Shells of Any Shapes.—Drawn shells of any shape—round, square, or rectangular—can be trimmed squarely and accurately, or trimmed with notched edges, in a single quick operation by using a Bliss flat-edge trimming press.   A trimmed and notched sample of square-edge trimming is sketched in Fig. 185.

The five sketches in Fig. 186 illustrate the die operations necessary for flat-edge trimming. At the left is shown the upper die which carries a filler pad free to float on its surface. The lower die is provided with a spring knockout pad, and a shell is shown placed on the pad, within the die, ready for trimming.

The punch, as shown, is provided on each side with stop strips which are ground true and parallel with the ground surface of the lower die. These strips clear the edges to be trimmed from the shell, when they descend with the punch and stop upon the die. In operation, the filler pad, in descent, enters the shell and depresses it to the required trimming depth in the lower die.

The press slide is cam driven and is designed to dwell at the completion of the downstroke during the trimming interval. A slight motion, sufficient for shearing off the scrap, is then imparted to the *lower* die, which cuts front, back, right, and left against the upper-die edges. By this action the scrap is sheared off and is ejected by an air blast when the slide ascends and the dies are opened. The side-trimming operations are shown in the third and fourth views (Fig. 186), and the end cuts are similarly made. The horizontal slide in the press bed, which imparts the shearing motions to the lower die, is operated from the rear of the press by a vertical shaft driven by miter gears from the main shaft.

Brehm Trimming Dies.—The Brehm trimming die, a patented tool, does flat-edge trimming of drawn shells in an ordinary single-action press. The actual shearing-off operation is similar in principle to the trimming dies
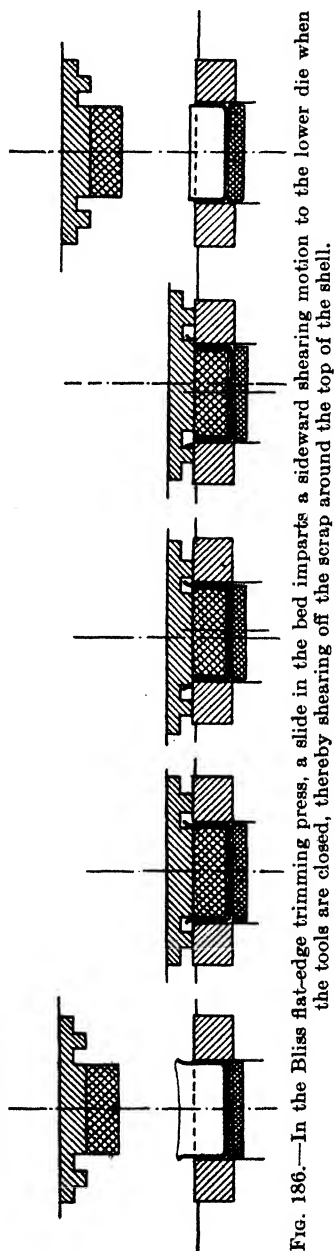
Fig. 186.—In the Bliss flat-edge trimming press, a slide in the bed imparts a sideward shearing motion to the lower die when the tools are closed, thereby shearing off the scrap around the top of the shell.

CHAPTER XVI

SECTIONAL DIES AND INSERTS

By the Use of Die Sections and Inserts, the Designer Often Simplifies the Problems Met in Making, Repairing, and Replacing Worn or Broken Units in Press Tools

Introduction.—Built-up cutting members have several advantages over the one-piece type: (1) easy making, (2) contours are easily changed, (3) new sections can be substituted for changed shapes, (4)
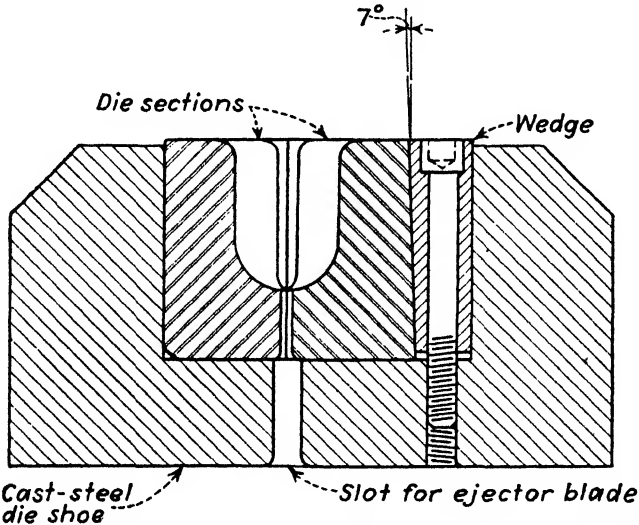
Fig. 188.—A cross section of a long rectangular die used for drawing heavy steel bumper guards is made in two sections forced tightly together with a wedge.

punch or die sections with nicked or sheared edges are easily replaced, (5) notching sections are easily installed, and (6) sections can be made and hardened that are impossible or impractical in a one-piece cutting member.

Die sections are likely to spread apart when blanking, forming, or drawing heavy materials; therefore, all sections must be positively and rigidly "backed" to avoid spreading. In built-up drawing dies, for example, the sections are sunk deep within the die shoe, usually the entire height of the sections, and are forced tightly together by inserting tapered keys or wedges, as in Fig. 188.

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Standard Shapes of Sections.—Standard shapes for punch and die sections have been commercially developed. By arranging the outlines of these sections in combinations, many different contours for cutting a large variety of blanks can be quickly produced. The usual cutting outlines of these sections are straight, square, or round cornered and arc segments. A cross-section view of a die using these sections is drawn in Fig. 189. At the left, a plan view shows the method of arranging the sections; the dashed line represents a portion of the outline, or the finished die. A large flange on each section provides means for rigidly securing the upper and lower sections on the punch holder and die shoe by using screws and dowel pins.
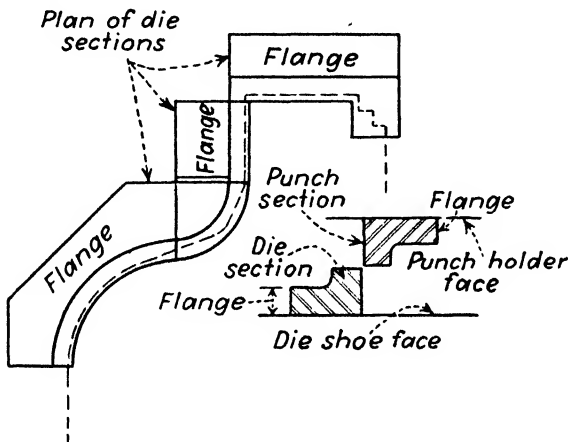
Fig. 189.—Standard commercial shapes for punch and die sections are used in making up the contours for large trimming and blanking dies.

When commercial die sections are not used, the sections are made of tool steel and without flanges. This avoids the unnecessary expense of machining flanges on to the blocks.

The blocks are of suitable widths and lengths to provide a generous area of base for inserting heavy screws and dowel pins. The sectional lengths must not be too long in relation to their width and depth, in order to avoid excessive grinding of warped blocks after hardening. The length also depends largely upon the contour shapes of the blocks.

The average size of a straight section is finished to approximately $1\frac{5}{8}$ by $2\frac{7}{8}$ by 12 in., but segments of arcs, corners, and rounds are made less than 12 in. long and of a more substantial area. An example of a compound sectional die for piercing and blanking and with sections made up as just described is given under Fig. 56.

Composite Die Sections.—Steel-clad sections are available in which the tool-steel cutting edge is welded on to a soft-steel flange.

A recent development by Jessop Steel Co. is the composite die section shown in Fig. 190. These sections are designed for small dies such as those used in the manufacture of toys, refrigerators, containers, and similar articles. The section consists of a tool-steel cutting edge
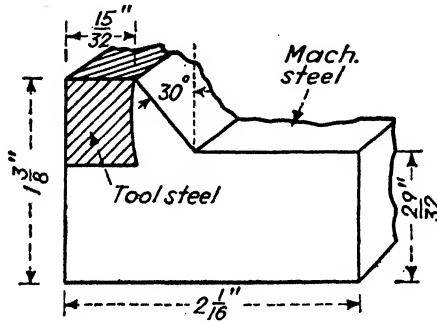
FIG. 190.—A rolled composite commercial die section for small press tools.

backed by soft steel. The advantage over solid tool-steel sections is that they may be hardened before drilling the dowel holes, thus eliminating lapping the holes and assuring a good fit in the dies. It is claimed that these sections may be bent to shape, either hot or cold, without destroying the weld.

Large Sectional Embossing Die.—The large die frame B (Fig. 191) is made of structural steel. The opening in the frame is flame cut and
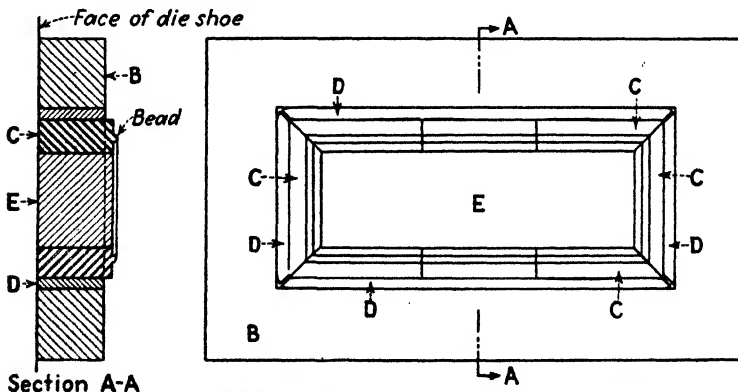
FIG. 191.—Precision members of sectional dies should be arranged so that the toolmaker can get out of difficulties if special fitting of parts should be needed.

is then machine finished. Eight hardened bead-embossing sections C within the frame are press fitted end to end, with miter joints at the four corners. Surrounding the beading sections are four lengths of cold-rolled steel filler sections D. Sections D back up the beading

sections and can be ground to fit closely around them. If the interior of the die frame is over- or under-size, the toolmaker can easily compensate for these variations in the final assembly by altering the thicknesses of the filler sections.

The punch sections, which carry the mating female sections, not shown, are arranged and held as described for those in the die. Screws

Fɪɢ. 192.—Wedges at the front and right retain four precision-made die sections in a recessed die shoe.

and dowel pins are inserted into all the different parts through the shoe below and through the punch holder above.

A machinery-steel center core *E*, which may or may not be necessary, is fitted within the eight sections. The whole design is now practically the same as if made from one piece.

Large Sectional Blanking Die.—The sectional die represented by Fig. 192 is designed for blanking large lamination segments for a rotor

having a completed diameter of 76 in.   Twelve segments are required
to complete the circumference for each layer of laminations, there being
an insulating gap of $\frac{1}{16}$ in. between the ends.

Four tool-steel-clad die sections are used.   The sections are immov-
ably locked in all directions by notched and anchored shoulders and are
placed within a deep receptacle sunk in the die shoe.   Die sections are
retained by one wedge section at the front and another at the right.
Socket-head cap screws enter each section at essential points, with
their heads in counterbored holes under the die shoe.   Two die inserts
are also shown at *A*.   The punch, not shown, is also built of steel-clad
sections which are "banked" securely around a solid center core.

A spring pad within the die is actuated through vertical pins *B*.
The lower ends of the pins rest on a cushion plate, which is the upper
part of a pneumatically operated unit secured in the press bed.   Work
pieces are prepared by shearing them into a convenient trapezoidal
shape.

The segments are limited by a tolerance of 0.002 in. for the width,
length, and radius of the piece.   Sizes of the punch and die are deter-
mined by using precision-made templets.

Small Sectional Dies.—Certain types of comparatively small rec-
tangular blanks which have straight-lined interior openings and are
made of light-gage materials, such as lamination blanks, constitute a
class of die work in which the most effective tool construction is inter-
locked die sections and one-piece punches.

In Fig. 193 the work piece is the pierced and blanked lamination
shown at *B*.   This sectional die pierces six mounting holes and four
elongated slots; and then by cutting across the center of the blank on
die edge *C* in the last station, two completed blanks are finished.   The
width of the material strip is the same as blank length *L*.

All the die openings are section lined.   The punches are the usual
one-piece types and have nothing in common with die sections; they
are therefore omitted.   The stripper plate, a positively attached chan-
nel-type construction, under which the strip passes over the dies, is
omitted for clarity.

The strip is entered at the right of the die by unwinding it from
"reeled" coil stock.   The forward end is registered against the first
finger stop, which has been depressed, while the punches in descent
pierce the six mounting holes at the first station.   The first finger stop
allows a waste of $\frac{1}{16}$ in. for trimming the end square when advanced
against the second depressed finger stop, where the end is sheared off
on die edge *D*.   In the second station, four elongated slots are blanked
through at the time the end is trimmed.

The strip end finally registers against the positive stop *E*, in the third and last station, where the blanks are sheared apart on die edge *C*. The forward blank slides down the ramp at the left, while the second blank passes down through the die opening between edges *C* and *D*.

The strip is now ready to be run at production speed with the "press open," that is, with the clutch treadle continually depressed. The strip is steadily advanced by an automatic roll-feeding device,
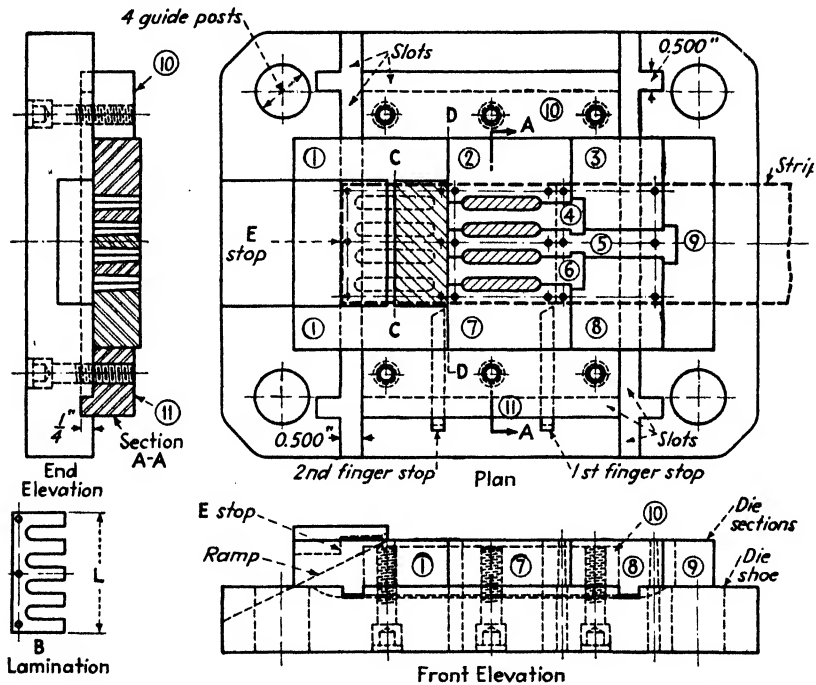
FIG. 193.—The construction of small sectional dies for thin blanks.

which pulls the stock from a loop maintained in front of the reel. Between the reel and press the strip passes through a pair of lubricating rolls which distributes oil on both its sides; this prevents excessive wear in the dies caused by bare metal contacts between cutting edges. Strip lubricant adds greatly to the longevity of cutting dies. The foregoing press accessories are illustrated in Figs. 13, 15, and 21.

Making a suitably compact arrangement of small "hooked-together" die sections is always an interesting job; it suggests the once popular jigsaw puzzle. The figure presents one of several methods for retaining small die sections. One feature is the four slots, $\frac{1}{4}$ in. deep and $\frac{1}{2}$ in. wide, sunk within the surface of the die shoe.

The slots form a rectangle on the die shoe, and the corners are crossed for cutting clearances. Die sections 1, 3, 5, and 8 have projecting tongues underneath them which fit closely within the slots, as indicated in the front elevation. On both sides of the die borders are long retaining sections, 10 and 11, which are likewise provided with tongues that fit the slots, shown in section *A-A*. It is a simple matter of assembly to grind the retaining faces of sections 10 and 11 to suit the lateral positions of the interior sections that lie between them.

The longest interior section is No. 5; it is "shouldered" over Nos. 3 and 8 and is notched at another place to admit the shoulders of Nos. 4 and 6, while the latter sections are also retained by Nos. 2 and 7. Section 9 is simply an attached "filler block" to provide easy entrance for the material strip. This block is sometimes extended at the right and up to within 1 in. from the feeding rollers.

Socket-head cap screws and dowel pins are inserted through the bottom of the die shoe and enter all the sections at essential points. Six of these screws are shown in sections 10 and 11. In each section, all the machine cuts and grinding directions are straight, which simplifies fabrication and construction. When grinding the die surface for sharpening, all the sections are reduced together, including Nos. 10 and 11.

Fig. 194.—Inserting a blade across a die opening.

An Insert across a One-piece Die.— A design for a blade insert is given in Fig. 194. Such inserts are sometimes needed for cutting off or forming the work in a final progressive die station. Another method is to make the insert extend through between the die blocks *A* and *B*, as indicated by the dotted lines. The whole die then consists of three sections. This design has other variations. It may be desirable to omit section *A* and attach the blade to section *B*, with horizontally positioned screws and dowel pins. It depends on the die operation required at the station.

Two Varieties of Die Inserts.—Die inserts are ordinarily of two distinct varieties. One type is shown in Fig. 195 at *A*; the other more common type appears in the same figure at *B*. Both types are press fitted into the die block; but if the insert is large enough, it can be held by screws from beneath the shoe.

The purpose of the insert at *A* is for enlarging a small die opening to facilitate working out and filing the interior contour through a deep

block. The die block carries a portion of the die outline, and the insert edge carries the remainder. The small size of this die opening is indicated by the given dimensions.

The purpose of the insert at B is to provide a small projection that extends into a comparatively large die opening, the extended end of the insert being shaped to become a part of the larger die contour itself. Die inserts can easily be replaced if—after press operations—they develop wear or become nicked or broken. Die inserts A and B are retained in parts of round holes; the centers of the holes are accurately

Fig. 195.—In this small portion of a seven-station die for producing a double row of blanks, two types of inserts are used: a large one as at A to give filing access to a small die opening, and a small weak projection as at B, which is cheaper to make and replace than if made solid in the die contour.

located by using a system of "stepped dimensions" for a jig-boring machine.

Four straight sections can be inserted vertically from the bottom side of the die block and then securely locked with a key, as shown in Fig. 196. At A, one of the sections is shown separately. The sections are milled from one piece of sufficient length to cut off four equal pieces. The pieces are then hardened and ground. The idea here is to provide the three small close-together rectangular openings shown on the surface of the die block.

In the cross-sectioned view, the four straight sections S are shown inserted from the bottom side of the block into a previously prepared rectangular hole. The sections lie at an angle of ¼ deg.; the angle, of course, provides the die clearance for the rectangular holes. The last

insert K is a wedge key and is press-fitted tight, thus locking together the entire group of inserted sections. The flat sides of the block, together with the projecting ends of the sections, are then surface ground flush. The $\frac{1}{4}$-deg. angles are greatly exaggerated to present this principle clearly.
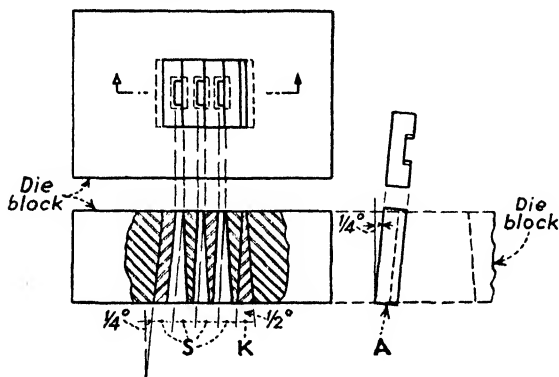
FIG. 196.   FIG. 197.

FIG. 196.—Small close-together openings in a die block are made by inserting light sections through the die block and locking them with a wedge.
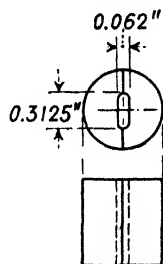
FIG. 197.—Greater accuracy in small die openings can be obtained by grinding the form in halves in a split bushing and then press-fitting the bushing into the die block.

A "split bushing" (Fig. 197) is separated in halves for grinding an elongated die opening or other internal shape. This method is often used in precision die work when great interior accuracy of small die openings is necessary. After grinding, the bushing is press-fitted in its proper location in the die block.
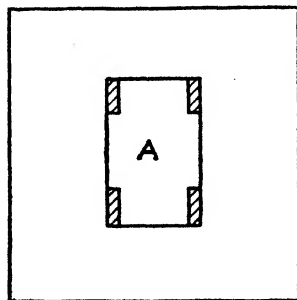
FIG. 198.—Die insert for small rectangular die openings.

Figure 198 shows the method for obtaining two or more square or rectangular die openings by using one die insert A. The cutting sides of small openings are thus exposed for filing, grinding, or lapping before assembly.

BENDING, FORMING, EMBOSSING, AND FOLDING

Accuracy of Bend Location Depends on the Type of Die Chosen—V-benders for Ordinary Parts, and Spring-pad Tools for Precision Work

A Die Designer Can Often Choose a Principle That Forms the Job in One Operation Instead of in Two or More Commonly Used Setups

Introduction.—Bending dies produce only one of the many functions that constitute the cold-forming group of dies and roll-forming machines. The function of a bending die is to change the normal plane of a blank into different directions.

In the cold-forming range of operations are bending, beading, twisting, flattening, swaging, riveting, bulging, upsetting, necking, flanging, curling, seaming, wiring, roll forming, and many others. In all these operations there occurs a forced internal local movement of metal directly attributable to plastic deformation. Deep drawing does not properly belong in this class. In deep-drawing operations more than local deformations occur. In drawing dies, the punch, in forcing the blank into the die and around itself, causes the blank to alter its shape radically. In producing a deep cylindrical shell, the metal is forced into an increasingly higher degree of plastic flow the deeper the punch descends. In forming operations, plastic flow may reduce the thickness of the metal or increase it. Its capacity either to stretch or to upset should be about equal. In other words, a metal that will draw well should upset well.

To understand the art of the pressworking of metals thoroughly, it is necessary for us to visualize just what changes occur inside the metal. The structure of metals is of two kinds: granular and cellular, or stringy. Cast iron and lead are the two extremes of granular and stringy, but neither of them will draw—one because it will not stretch at all, the other because it will stretch too much, locally. This indicates that we need both ductility and strength but not hardness in materials for drawing. Hardness is induced in any metal by working it. To illustrate: Take a narrow strip of soft copper, bend it at right angles, and you have work hardened it so that it cannot be bent again at the same place or straightened by hand without annealing. Take the same strip and slap it down on a surface plate several times, and

then note the difference in temper. What have we done that such a simple procedure should harden it? We suppose that there is an explanation clear to a metallurgist, but his conclusions would not help us to visualize pressworking conditions.

Bending a piece of metal on a small radius stretches it on the outside and compresses it on the inside. Between the two is a neutral line, or zone. If bent to a large radius, the outside stretches, and the inside remains practically normal. Bending displaces the granular structure, and the grains will not slide again until the "slip planes," as they are called, are again arranged in the proper order. This is done by annealing. As we know, metal expands under heating, and for our purpose we can visualize the metal as loosening up and allowing the molecules, or grains, to readjust themselves. That this mental picture is largely true is shown in the structure of stainless steel. The standard mixture of this metal is 18-8; this means 18 per cent of chromium, 8 per cent of nickel. The carbon is about 0.05 per cent. A casting of this mixture will withstand a dilute sulphuric acid bath, but a rolled strip of the same metal will not.

Rolling apparently gives metals an entirely different structure, a laminated one. The grains of chromium, nickel, and iron appear to be held together with a binder of iron oxide. Let us take a piece of sheet metal, say $\frac{1}{8}$ in. thick, polish it, and then immerse it in a weak solution of sulphuric acid for some time; when we take it out, no difference in appearance is discernable. It is still polished; it has the same volume; and its weight is the same as before the acid bath. Notwithstanding its unchanged appearance, we find that if we drop it on another metal surface it has no more "ring" than a piece of lead. If we try to bend it, it falls apart because it is so rotten. Why? Because the iron oxide that held it together has been dissolved out of the structure, and there are spaces between the grains of chrome, nickel, and iron. The layers in wrought iron are another good example. The layers of iron and slag can be seen distinctly with the naked eye. It is because of this structure that wrought iron works so easily under a hammer and does not "work harden" or crystallize but at the same time will slip under pressure.

There is at times some confusion in the nomenclature of drawing and bending and forming dies. A forming dies comes within the general meaning but not within the specific meaning. A bending die forms angles. It may operate upon projections, or it may bend the entire width of the blank. It may partake of the nature of a drawing die because it bends up projections on one or several sides of a blank by forcing the blank through a die. Usually, however, the center of

the die is filled with a registering pad which elevates the work out of
the die when the ram ascends.   A bending or forming die raises any
portion of a blank above its original plane or makes bends in more than
one direction at the same time.

A bending or forming operation may be anywhere up to an angle
of 180 deg. and may require more than one die.   The inside corner
of the bend may be sharp, or it may have a specified radius.   Usually
this corner radius is large enough to prevent undue weakening of the
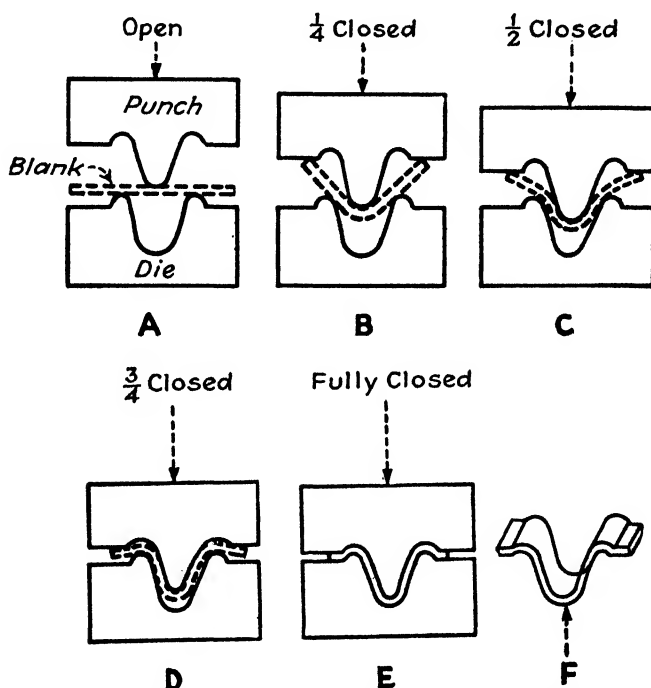
FIG. 199.—The free ends of the work follow paths of least resistance, while forming
follows the punch contour.

metal by either stretching or indenting or to fracture it because of low
ductility in the metal or the direction of its grain.

Bending and Forming Analyzed.—The general principles of bend-
ing and forming operations are shown in the several "slow-motion"
views (Fig. 199).   At *A*, the face of the blank is in contact with the
punch, which is descending to make the first bend.   The finished piece,
which involves bending, curling, and forming, is shown at *F*.

At *B* the punch starts the first bend across the center of the blank.
The free ends of the blank are "thrown up" against the faces of the
punch.   At *C* the blank begins closing against the sides of the punch

and starts curling toward the ends. At D the work hugs the sides of the punch closely, and the curled ends are almost finished; at E the work is completely formed and spanked to size at the bottom of the stroke.

These simple operations reveal two important principles found in

FIG. 200.—For many pieces it is unnecessary to work out the die form in the die block, because the work follows the punch contour.

bending, forming, and drawing dies; namely, (1) movements in the work material follow the paths of least resistance, and (2) the shaping of the work follows the punch contour.

The use of the second principle is seen in Fig. 200. Working out the complete form in the die block is unnecessary if flanges of the blank still remain on the die block after forming, as shown.

V-benders and "Spring-back."— V-bending dies are the simplest of all die benders. One of them is sketched in Fig. 201. If both the punch and the die members are made with 90-deg. angles, as shown, the angle in the finished work will be greater than 90 deg. This discrepancy is caused by spring-back of the material, resulting from its residual resiliency. The amount of spring-back varies with material and thickness. In dead-soft steel it may be only $\frac{1}{2}$ to 1 deg.; for hard-rolled steel, 4 to 5 deg.; and for hard brass or phosphor-bronze sheet, it may reach 12 to 15 deg.

Spring-back is overcome by bending the work to an angle *less* than the angle wanted. This determination is always a matter of experiment by the toolmaker. Angular spring-back is sometimes avoided in thick metals by rounding the V in the die to conform with the outside bend on the work. The sharp angle on the punch is made

FIG. 201.—Spring-back of the material prevents this die from producing a true 90-deg. bend.

about 1 deg. less than the die angle. The punch, in descent, then scores a line in the finished bend, thus setting the metal over a positive support.

Pieces formed in V-bending dies are not always precision work. It is difficult to bend two pieces exactly alike in these dies. The variation is caused by slight horizontal movements of the blank while bending and by variations in the stock temper.

One of several methods used in attempting to produce precision bends is shown exaggerated in Fig. 202. The punch angle is made more acute than the die angle, so that the punch produces a definite set in the work at the bottom of the press stroke. Another exaggerated
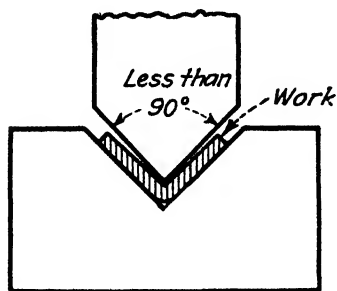
Fig. 202.—The punch angle must be reduced to overcome spring-back in the material.
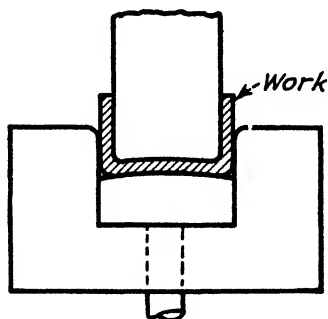
Fig. 203.—The spring-back of a convex bottom across a piece overcomes the spring-back at both sides.

case is shown in Fig. 203; here the bottom of the work channel is formed sufficiently convex to straighten the sides of the channel to the required angles, this occurring when the convex surface springs back upon removing the work from the die.

Using the spring-back tendency, across the bottom of the piece, to overcome another spring-back in the sides is one example of utilizing
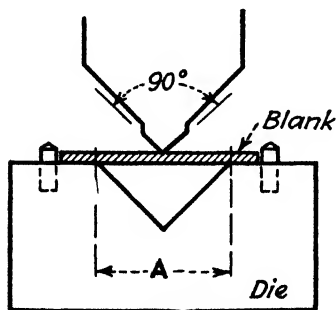
Fig. 204.—In V-bending dies, distance *A* has an important effect on finished results.
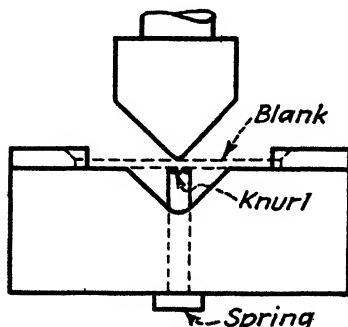
Fig. 205.—Side creep of the blank in bending is prevented by the knurl-faced spring pin.

an opposing mechanical law by reversing your practice and compelling it to work for you. Fortunately, we can sometimes take advantage of such unfavorable conditions and force them to serve us. However, if angular bends must be very accurate, and spring-back is difficult to

control, it is advisable to employ a second operation sizing die and re-form the angles.

In the operation of the V-bending die (Fig. 204) distance A has an important effect in bending results. When A is too short, an imperfect angular bend is produced. Distance A and the width of the punch should be sufficient to insure a definite set in the work angle at the com-
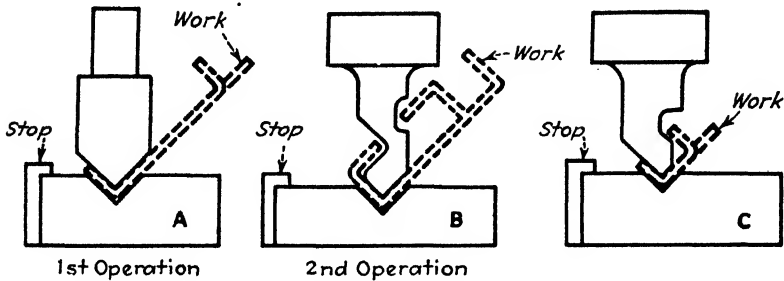
Fig. 206.—By cutting side clearances at necessary locations in the punch, the same tool can be made to serve for several bends in the same work.

pletion of the press stroke. Dimension A, in practice, should not be less than twelve times the work material thickness. It should be fifteen times the thickness, if the material is $\frac{5}{64}$ in. thick or less.

In the V-bending die (Fig. 205) a vertical spring-pressure pin with a knurled face prevents side creep of the work when the punch descends.

Three common applications for V-bending dies are shown at A, B,

Fig. 207.—Increasing angle A on the bending punch decreases the pressure required to make the bend.

and C in Fig. 206. These illustrations suggest the endless variety in the design and use of such tools.

Side Bends.—When bending, as shown in Fig. 207, it is obvious that as angle A on the punch face increases, the bending moment decreases. In practice, angle A is usually made 5 to 10 deg. In bending long arms, angle A may be increased to a point where a press having a greater crank stroke becomes necessary.

The only reliable data for the necessary pressure to be used in bending and forming are those derived from actual tests. A book covering the subject and entitled "Press Work Pressures," by C. W. Lucas, has been published by the McGraw-Hill Book Company, Inc., New York. This book shows hundreds of bending and forming conditions. Formulas based on actual tests were also published under the title "Pres-

sures for Right Angle Bends in Steel" (*American Machinist*, vol. 82, page 1017).

A die for bending a right angle of greater precision than possible with a V-bender is sketched in Fig. 208. The finished piece is shown at *A*. Spring pad *B* first descends and holds the blank flat, while the punch *C*, continuing in descent, bends the right angle over the left-hand edge of the die block *D*. The blank length is a fit between stops *E* and *F*; therefore, dimension *G* is always constant.

With this die, the spring-back is little or none, but with a V-bender it might be 4 to 6 deg. The reason for this is that punch *C*, confined by heel *F*, "irons" the "skin" on the outside of the angle, thus normalizing the work strains. If the work angle must be greater or less than
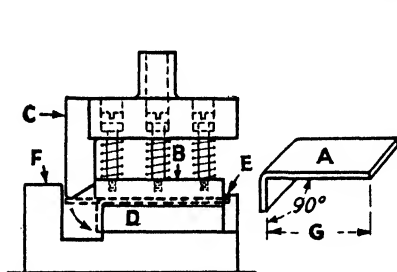
FIG. 208.—Horizontal type of bending die in which length *G*, on the work, is constant.
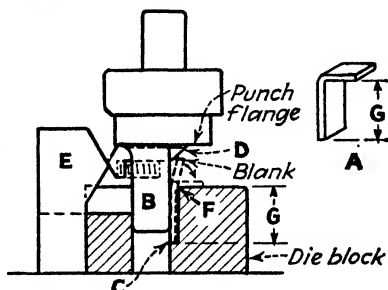
FIG. 209.—Vertical type of bending die in which length *G*, on the work, is constant.

90 deg., this condition is obtained by providing the necessary angle between the faces of *B* and *D*.

Another method for making accurate bends is illustrated in Fig. 209, with the finished piece sketched at *A*. The tool is shown partly closed. When the ram is up, the blank is placed vertically against the right-hand side of punch *B* and is then dropped into a bell-mouthed slot in the die block. The slot bottoms at *C*. When the ram descends, the angle on the face of horizontal pin *D* is forced, by contacting the positive cam *E*, to start the bend against the die edge *F*. Continuing in descent, the flange on punch *B* completes forming the angle at *F*, while the end of the blank is always in pressure contact at point *C*. The result is a completed angle in which the length *G* is constant.

Pin *D* is caused to withdraw by a spring, after it passes the high point on cam *E*, and clears the punch flange before the flange reaches its lowest point, where it spanks the work to size. When the ram descends, if pin *D* is clogged or fails to recede because of a broken spring, it would be driven back when its angular face contacted the bend at *F*, and no tool damage would result.

It is impossible to place two blanks in this die at one time, a mistake that sometimes happens with disastrous results in bending and forming dies of other designs. The design and operation of this tool are somewhat similar to the press-brake principle in which the lateral length of work may be several feet.

The Spring-pad Principle.—The usefulness of spring pads in bending and forming dies is shown in Fig. 210, in which the press stroke is down. The blank is placed within a nest of four notched plates *A* and lies flat across spring pad *B*, which is flush with the die face when the
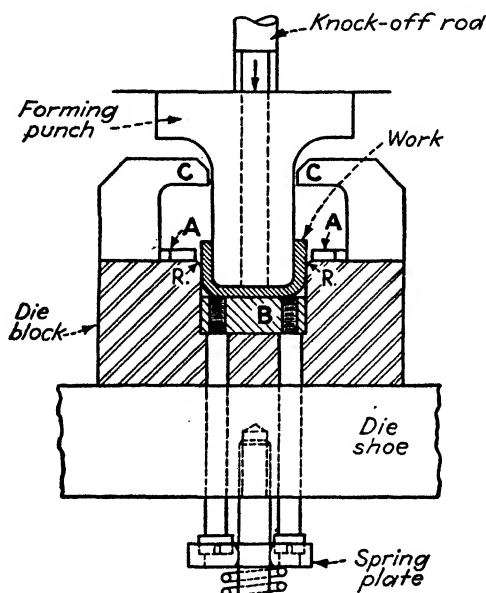
Fig. 210.—When the punch ascends, work can be stripped from the punch either by "sky-hooks" *C*, or by a knock-off rod.

stroke is up. When the forming punch descends on the blank, the pad and work recede together, thus "throwing up" the ends of the blank within the sides of the die. At the bottom of the stroke, the pad registers on the floor of the die opening, and the punch then gives the formed work a definite set.

The spring pad is actuated by a spring-plate "bumper" beneath the die shoe. When the ram ascends, the spring pad causes the piece to follow up the punch until the pad is again flush with the die face. As the ram continues to ascend, the work is removed from the punch by contacting the two stripper hooks, or fingers, *C*. If stripper hooks interfere with placing the blanks, the knock-off rod shown can be

employed instead.   When output is sufficiently large, a magazine can be used to feed the blanks into the die.

Reverse Bends.—Bending in opposite directions simultaneously is easily accomplished by using the principle set forth in Fig. 211.   For bending pieces, such as shown in Fig. 212, the blank is laid on the face of die channel *A*, between the end gages *B* and the four side pins shown in section *X-X*.

When the ram descends, two spring pins through punch *C* contact and hold the blank, while bending punches *D* start bending down the ends of the work.   Punch *C* then contacts the blank and carries it
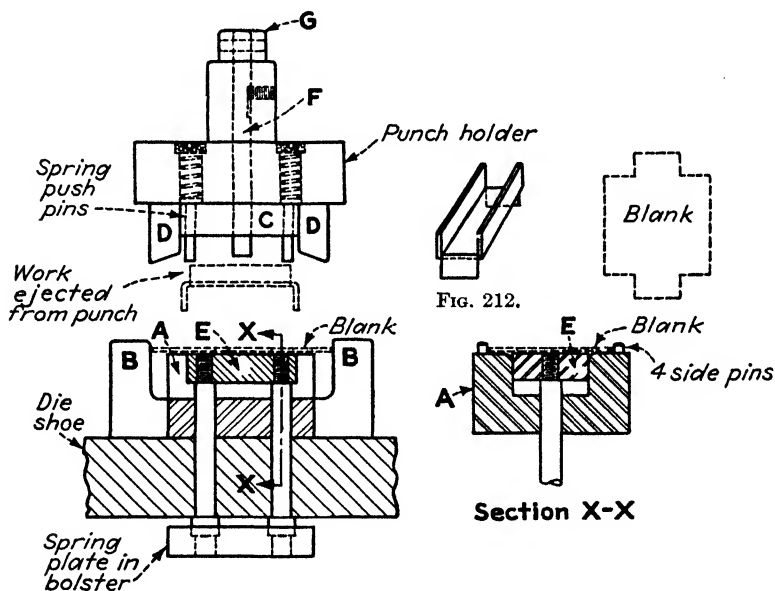
Fig. 212.

Fig. 211.

Figs. 211, 212.—Side punches *D* form the ends down, and punch *C* pushes the work into the die channel *A*, to form up the sides of the part sho vn in Fig. 212.

down into the die channel *A*, against spring pad *E*.   This action "throws up" the sides of the work against *C* and thus forms the channel.   When the spring pad registers in the bottom of the die, the work is spanked to size and shape.   Near the top of the stroke, knock-off rod *F* contacts the bar through the press slide and strips the finished piece from the punch.

If the press is operated by the diesetter when the knockout bar is set too low, stop block *G* prevents injury to the rod mechanism.

In forming dies as just described, if the push-off springs are strong enough to strip the work from the punch when the ram ascends, the

work will remain clinging on the pad.   This is an unwanted condition, because it is then necessary to "pick off" each piece, which would be a slow operation.   On the other hand, the push-off springs are purposely made of insufficient strength to strip the work, and the piece is carried up clinging on the punch for ejection by the knock-off rod.   The piece then falls behind the press as desired. ˙ This principle is one that must always be considered by the designer when disposing of formed pieces of work.   It may be necessary to " iron " the formed-up wings to cause them to adhere firmly on the sides of the punch.

Cutting Off and Bending.—A cutting-off and bending die for forming a bracket in one operation is shown in Fig. 213.   The bracket is

Fig. 213.—When this cutting-off and forming die is used on an inclined press, the ejected work slides off to the rear.

formed over the positive punch *B*, when the positively attached forming die *F* descends and cuts off the strip at both ends, between blocks *A* and *E*.   The work is first advanced under the positive channel plate *C* and stops against pin *D*, where ¼-in. waste is cut from the strip to obtain the rounded corners on the work.   The top surfaces of *A*, *B*, and *E* are in a horizontal plane.

When member *F* cuts the strip to length and bends the free ends of the blank down over punch *B*, it banks on the work at the completion of the press stroke and spanks the angles square.   Four inserted pins *I* guide the blank straight while forming.   Upon ascent, the die carries up the work, which is ejected by pad *G*.   Punches can be arranged to pierce holes in the work, through die block *A*.

Combining Bending Operations.—Figure 214 illustrates the method for bending four angles, as at *A*, in a previously cut blank.   The tool is

shown in three stages of operations at *B*, *C*, and *D*. At *B*, the die in descent is in contact with the blank. At *C*, the die has completely thrown up angles *E* on the work. At *D*, the die has reached the bottom of the press stroke, the entire piece is completed, and all the angles have been spanked square. A knockout rod ejects the piece from the die when the ram ascends.
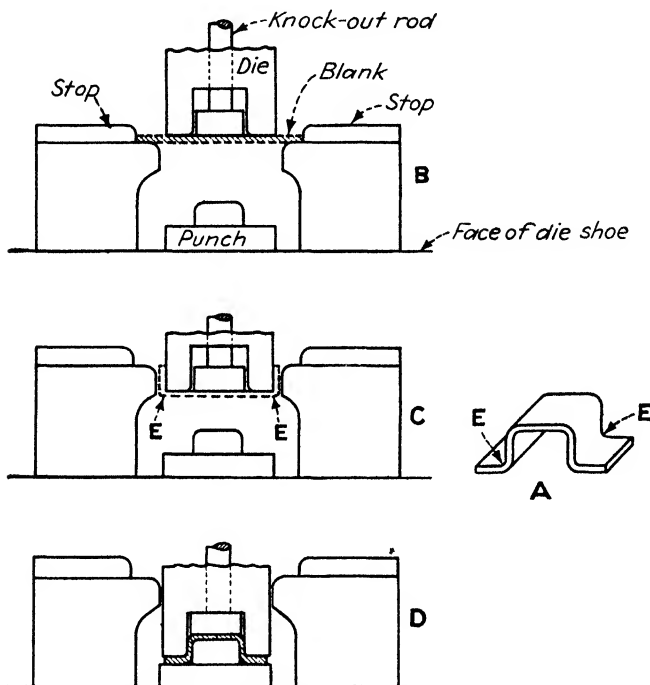
Fig. 214.—This single forming operation, shown in three views, is a principle often overlooked, and two dies and two operations may unnecessarily be made, which slows production.

Forming Brackets Having Four Angles.—Figure 215 shows a spring-pad die for bending and forming a four-angled bracket. The blank before bending is shown in view *A*, dashed across the die between the locating gages. At *B*, the operation is shown completed. In dies of this variety, it is always best to make one or two "slow-motion" sketches as a precautionary measure, to determine the probable movement of the metal while forming takes place.

At *A* the sketch shows the forming conditions when the punch has descended halfway. From this sketch we learn that the work is not produced by bending but is being drawn and curled into the die over edges *C*, with the wings dragging under punch radii *R*. This condition

is not recommended for thick blanks; it would require heavy punch pressure, and the work would probably be drawn to oversize lengths. For stock less than about $\frac{1}{16}$ in. thick, the results are usually satisfactory. This forming principle is encountered frequently in dies of
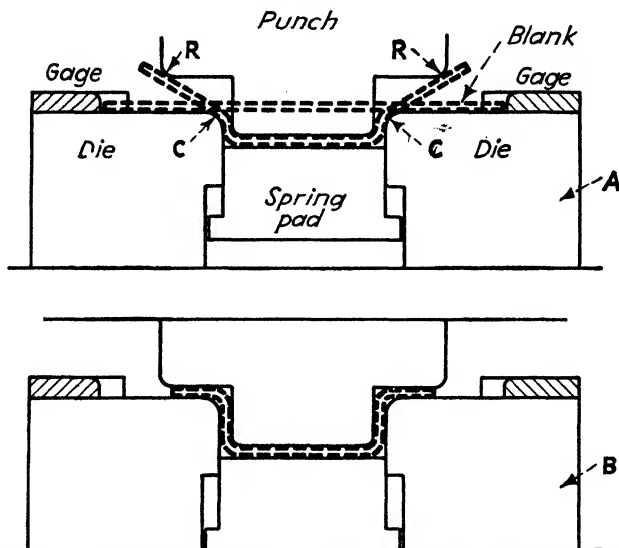
FIG. 215.—A spring-pad forming die for producing four-angled brackets.

other designs, and it should be thoroughly analyzed by making several tryout sketches before adopting it for precision work.

Side-forming Cams.—A die with side-forming cams is sketched in
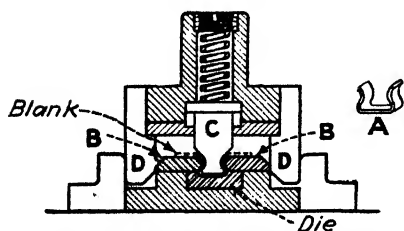
FIG. 216.—A blank placed on the slides *B-B* is pushed down between them by punch *C* to form a *U* shape, and the slides are then advanced by side punches to form the ends of the part.

Fig. 216, together with the finished piece *A*. The blank is positioned between stops, not shown but fastened on the tops of the side-forming cams, or slides, *B-B*. When spring punch *C* descends on the blank and before the side punches *D-D* contact and start moving in the slides, the work is thrown up U-shaped between the noses of slides *B-B*. The punch then carries the U-shaped work down on the face of the die. The ram, continuing in descent, compresses the spring above the punch and simultaneously forces the side punches *D-D* to advance the side-forming cams inward. At the bottom of the press stroke, as shown, the bottom and sides of the work

are spanked to size.   At the top of the press stroke, the formed piece is pushed from the punch with a hand tool.

Self-stripping Collapsible Punch.—A collapsible punch is a convenience when forming and stripping deep bends, as shown in **Fig. 217.** The punch is shown collapsed at A; but when it descends on the blank,
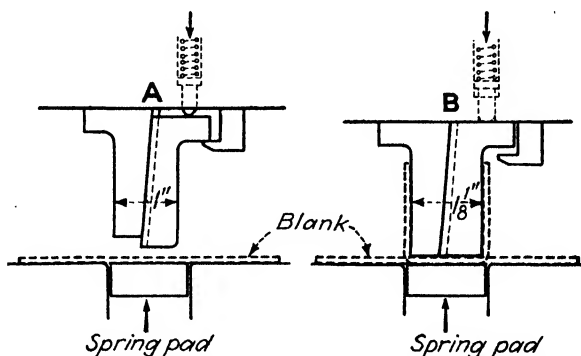
Fig. 217.—On the upstroke, the punch collapses, and the formed part is left standing on the spring pad.

over the spring pad, it is forced to expand full width, as seen at B.   The ends of the blank are thrown up by further punch descent.   On the upstroke the punch collapses as it leaves the work, and the finished piece is left standing on the pad.
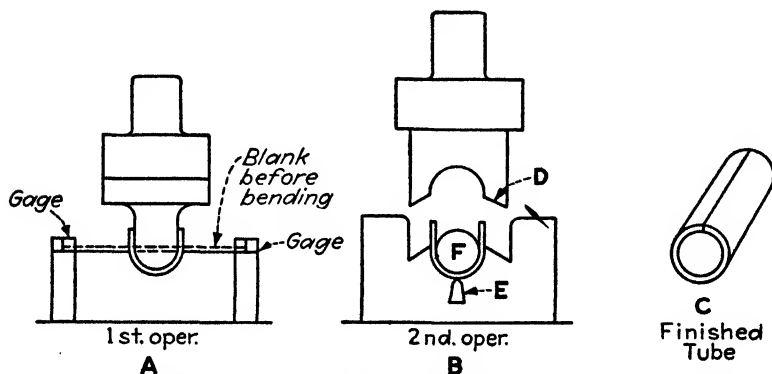
Fig. 218.—A marking punch E scores the outside of the tube being formed, which relieves spring-back and causes the ends of the tube to close tightly.

Forming Circular Tubes.—Figure 218 shows one method for forming a circular tube in two operations.   In the first operation at A, the blank is located between the gages; and when the punch descends, the blank is formed U shape.   In the second operation at B, the tube is completed as shown at C.

In the second operation at *D*, the angular faces on the punch in descent contact the free ends of the U and close them together; the ends readily enter the punch opening, because of the angles. At *E* is an inserted marking cutter which relieves the spring strain in the formed piece and causes the ends to form tight together. *F* is a removable mandrel.

There are several objections to forming a tube in this manner, especially if precision work is expected. If the marker is discarded because it scores the tube, it will be found that the ends will not close together tight. There will be a gap of 0.005 to 0.015 in. between the ends, because of spring-back.

· Another fault is that the tube may twist in forming; thus, the ends of the tube will not have flush surfaces. A remedy for both these faults is to force the finished tube through a sizing ring with a shouldered punch, the arbor of which extends through the tubular hole. The hole through the sizing ring is slightly tapered inward toward its delivery end, the same as in a burnishing die.

In this type of sizing die, the tube is forced through a bell-mouthed sizing ring, or bushing, horizontally. The horizontal punch is reciprocated by a side cam attached to the punch holder, and the pieces roll into the die from an inclined magazine. They are stopped in front of the punch ready for insertion through the die. The sizing ring floats in a holder and has about 0.010 in. floating clearance. It aligns itself instantly when the work, on the punch, enters it.

A quick setup for sizing tubes is found in using a shaper for a punch press. The sizing ring floats in a holder block secured in the shaper vise. The shouldered punch is secured horizontally in the face of the ram and in line with the sizing ring. The many quick adjustments on a shaper that govern the length of stroke, ram speed, die space, and vertical heights are found convenient for many varieties of die work. Another advantage is found in using vertical magazines for feeding the work into the dies. For sizing, burnishing, or redrawing shells, the vertical magazine principle works out well.

Forming Flanged Tubes.—Figure 219 represents a bending and forming principle for producing in one operation the piece shown at *A*. This operation is usually done in two or more dies. There are other ways to produce this piece; for example, it could be formed in a die similar in design to the one shown in Fig. 216.

Bending Six Angles in One Operation.—Figure 220 shows a die for producing the six-angled piece shown at *A*. When the ram descends, the center channel of the work is formed in the die by spring punch *B*; the free ends of the work cannot be thrown up higher than the ends

of punches C. When the center channel is completed and the ram continues to descend against the spring, the punches C bend down the free ends over the die edges, the work is spanked square, and the operation is completed as shown in the closed position of the tool.

This tool must use very ductile light-gage materials, not over $\frac{3}{64}$ in. thick. The depth of the center channel must be shallow, because
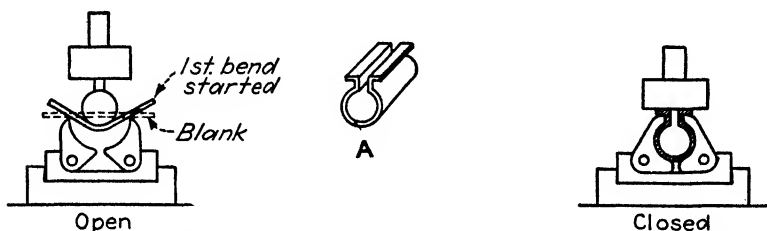
FIG. 219.—The swinging members in this forming die avoid using two dies and two forming operations.

the first channel sides are *drawn* into the die by the punch and forced to curl over the radii R. A similar principle was explained under Fig. 215. If the drawing depth is too great and radius R too small, the tensile strength of the material will be exceeded, and the work will stretch or fracture while forming.
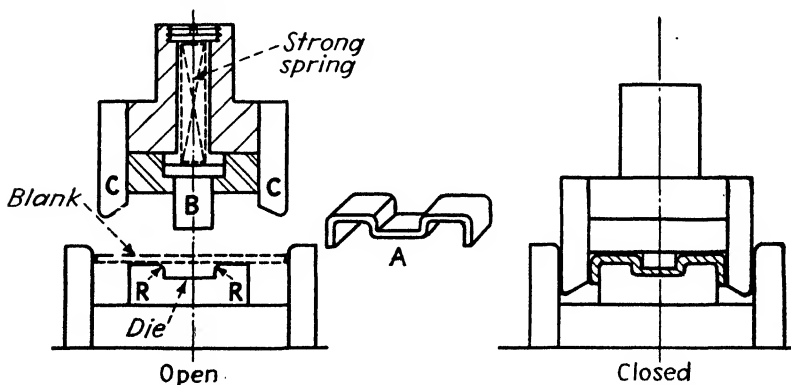
FIG. 220.—This die bends six angles at one press stroke, but it has faults similar to those shown in Fig. 215. It can be used for bending only light-gage ductile materials.

Bending Square and Rectangular Tubes.—Figure 221 shows a square tube C, formed in the same V-die in two operations, and slight variations are permissible. In the first operation the blank is bent and spanked to the shape shown between blocks B. When the punch ascends, the work is ejected from the die by a spring pad. If the pieces adhere on the punch, they are stripped off by installing a push-off pin or a knock-off rod.

For the second operation, the same lower die is used with blocks *B* and spring removed, and a different punch of suitable shape substituted. When the ram descends, the punch closes the free ends over arbor *A*. The arbor is removed from the tube by its handle.
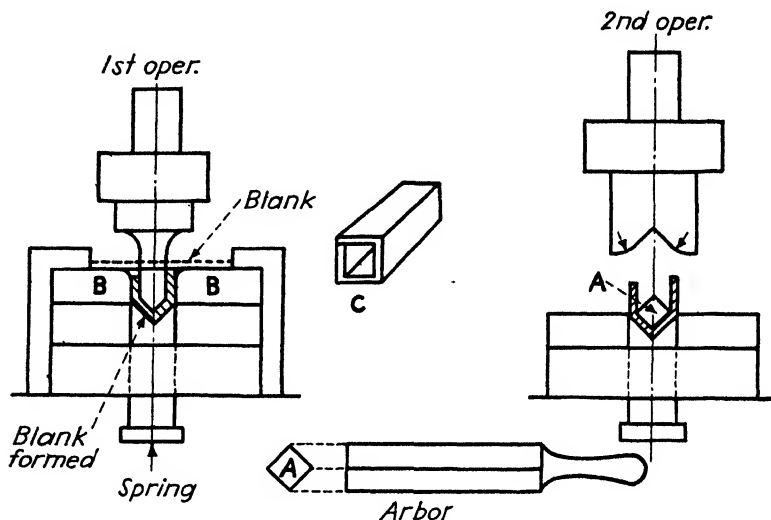
FIG. 221.—Forming square tubes in two simple operations.
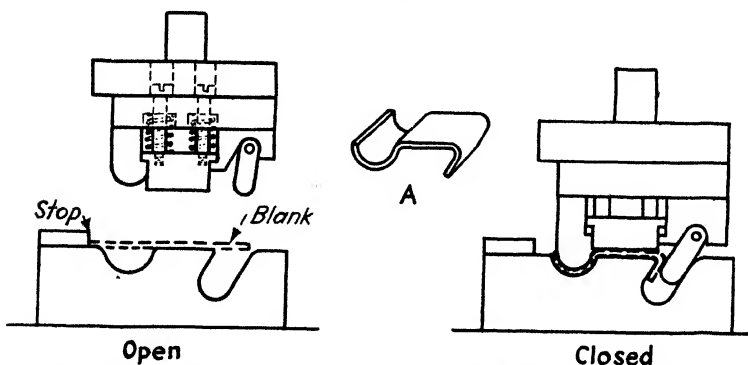
FIG. 222.—The two unsymmetrical bends on piece *A* are made in this die. When the ram descends, a spring-pressure pad holds the blank while the punches continue to descend and form the bends.

Square and rectangular tubes can be formed in single-operation progressive dies if the output is large enough to defray costs. An example of this was given under Figs. 129 and 130 in Chap. XIII.

Unsymmetrical Bends in One Operation.—Figure 222 shows combination tooling for producing two different bending operations simul-

taneously.   This tool uses the well-known principle of a swing punch, which is adapted for producing many other similar and difficult shapes.

Two forming dies for separate operations on the same piece are sometimes placed side by side in one press.   In loading the tools, the formed piece is removed from the first operation die and placed in the second die, and a new blank is then placed in the first die.   Thus, two distinct operations are performed in one strike.   However, this is sometimes a difficult setup, because the closed heights of both dies must be exactly equal.   Otherwise either one or both operations are not spanked at the bottom of the press stroke.
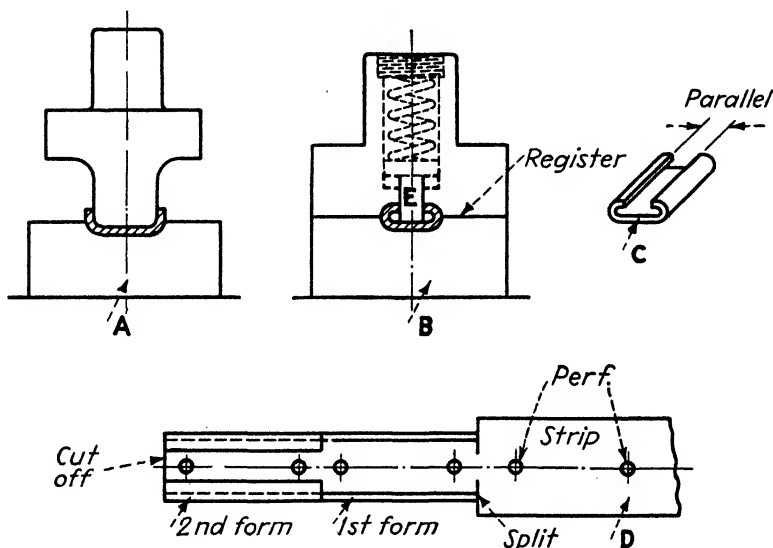
Fig. 223.—Curling designation strips singly and progressively.

Forming Designation Strips Progressively.—In Fig. 223 at *A* and *B* is one of the several methods for curling designation strips.   The first operation at *A* throws up the sides of the strip U shape.   In the second operation, the free ends of the U-strip are curled inward by the punch in descent.   The edges of the work are stopped parallel, as in sketch *C*, against the sides of spring punch *E*.   When the ram descends, the spring punch is in pressure contact on the bottom of the U, before the sides begin to curl.

It is possible to combine these operations in one tool and produce the work progressively, as shown by the strip *D*.   Mounting holes can be pierced and countersunk if necessary, previous to the first forming station.   Countersunk holes are produced with an embossing punch,

Forming Adjustable Collars in "Horn Dies."—Figures 224 and 225 are first- and second-operation dies for forming the collar ring sketched at *A*. First, the blank is cut to its developed length in another die, not shown, and the round and square holes are pierced at the time of blanking. In Fig. 224, radii *R* in the die are formed 0.005 in. less than
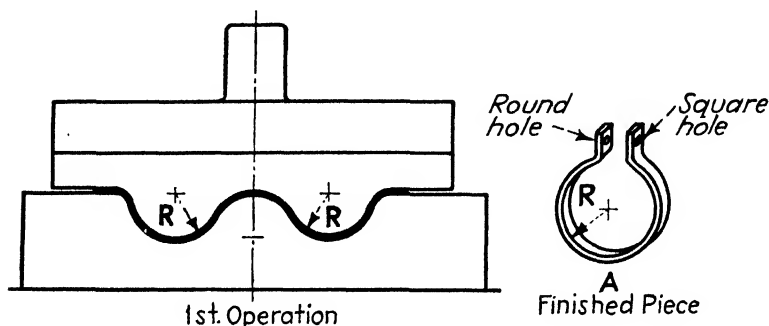
FIG. 224.—First-operation forming die for the piece shown at *A*.

R in the finished piece; this causes the ring to close slightly, as desired, after the last forming. In other words, it compensates for spring-back.

In the second forming die (Fig. 225) the first operation piece is represented by dotted lines sketched across the length of the die. The work is positioned on gage blocks *B*, touching the die block, as shown. Straddle gage pins are used for the lateral location.
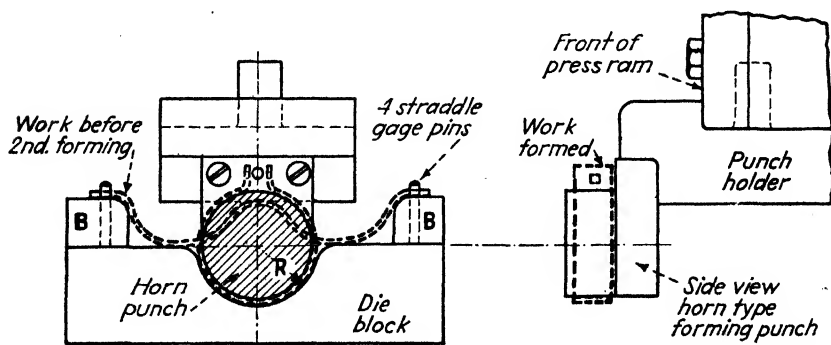
FIG. 225.—Die and horn type of punch, for the second and last operation on piece *A*, Fig. 224.

For large work, dies of this type are usually "horn-type tools." The die set is special and extends out in front of the press ram, as shown. This design allows the punch holder to be offset higher and to extend up in front of the ram, gaining more die space. A horn punch is shown in Fig. 225 at the right.

Designing Large Forming Dies.—Figure 226 represents a quickly constructed forming die, a good design and inexpensive to build. In light manufacturing this tool is considered large work. The same method can be used for the construction of very large forming dies.

The formed work, shown at the right, is cold-rolled steel $\frac{3}{32}$-in. gage. All holes have been omitted from the work. The finished piece is a radio chassis and is made in large quantities.

In forming large sheets, the die must be composed of sections. A design must be discovered that will prevent the sections from spreading when the punch forces heavy material between them.
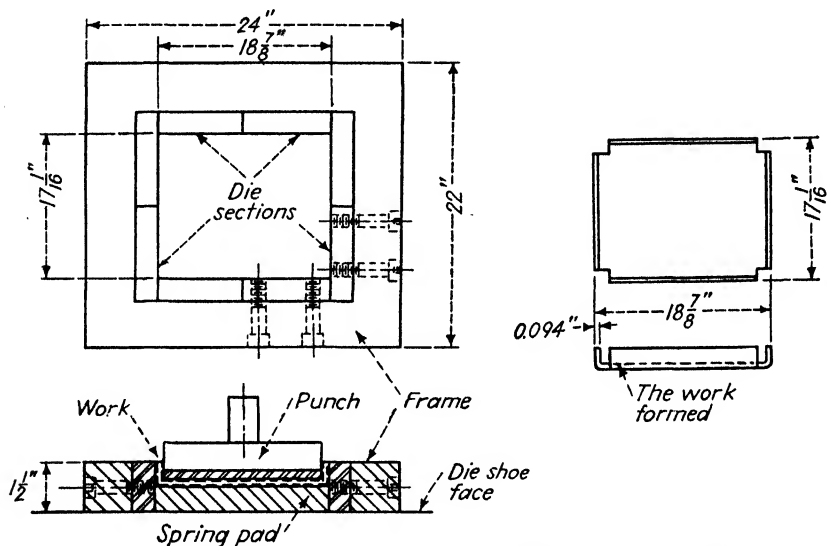
FIG. 226.—This large forming die is built of eight sections. Spreading of the sections is prevented by a strong retaining frame. This principle is applicable in other types of dies, also for compound piercing and blanking.

A one-piece frame encloses the die sections as shown in the sketch. The frame, structural-steel plate, $1\frac{3}{4}$ by 22 by 24 in., is first machined on one flat side to $1\frac{1}{2}$ in. thick. A rectangular opening is then burned through the plate by the acetylene-torch process and machine finished. The die sections are $\frac{5}{8}$ by $1\frac{1}{2}$ in., flat tool steel, backed up within the frame and attached with screws, as shown.

This construction is better than milling a recess in the die shoe and attaching the sections within. It is obvious that setting this frame on edges for drilling and counterboring screw holes is easier than similarly handling an irregularly shaped die shoe that may weigh 350 lb.

The piercing, trimming, and corner notching die for the blank is the reversed compound type. The one-piece frame principle is also

followed in designing this die. The frame that holds the die sections is attached on the face of the punch holder. The punch is a steel plate attached on the die shoe and surrounded by hardened-steel sections. There are 25 scattered bushed holes in the punch coincident with the piercing punches which operate through a stripper plate within the die. Four chisel scrap cutters are centrally located, one on each side of the punch; this avoids using a stripper plate around the punch.

Piercing punches are held by shouldered heads secured in a plate attached on the face of the punch holder, within the die opening. Blanking, forming, and piercing dies of similar designs are made in very large sizes; some are 8 ft. long and 3 ft. wide; others are even larger, as used in tractor and agricultural machinery plants.

In forming rough heavy blanks in which the gage thicknesses vary considerably, the forming sections within the die are separate blocks and backed up with either strong springs or stiff rubber. This construction permits the blocks to spread slightly, during forming operations, and compensate for variations in material thicknesses.

Although the tools just described are comparatively simple designs, they set forth principles that are applicable in many other forming jobs. The work may have long or short members to be formed up, possibly ribbed walls, instead of the straight walls as in Fig. 226. The aim is to present tool principles for general use, as far as possible, and not special designs for individual dies.
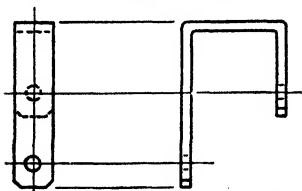
Fig. 227.—A terminal used in electrical industries, produced in a single-operation die.

Cutting off Blanks and Forming "U-shapes."—Forming operations often follow shearing. Figure 227 shows a typical U-shaped terminal produced in the die illustrated in Fig. 228. The piece is notched, pierced, sheared, formed, cut off, and ejected at a rate of 7,500 per hour. In a high-speed press this output could be increased tenfold.

This tool is a "no-scrap die," the width A of the strip being equal to the developed length of the blank. In operation, die block B is covered with a channel stripper plate which has been removed to show the plan. At the first station C two holes are pierced, and corners of the blanks are clipped off by punches with backing-up heels. The next progressive station is idle, providing sufficient steel to support the shearing edges D, in the die. The strip is then advanced against stop pin F, by a hitch or roll feed or by hand.

At the left of the die block is a pressure pad H, the springs of which are stiff enough to resist the light pressure necessary to form the work.

When the combination shearing, forming, and cutting-off punch *I* descends into the close-fitting slot *K*, the terminal arms are sheared *down* by the angular shearing edges on the punch, against die edges *D*. Continuing its descent, the punch forms the work over pressure pad *H* and within the punch opening *L*. A further descent depresses the pad,
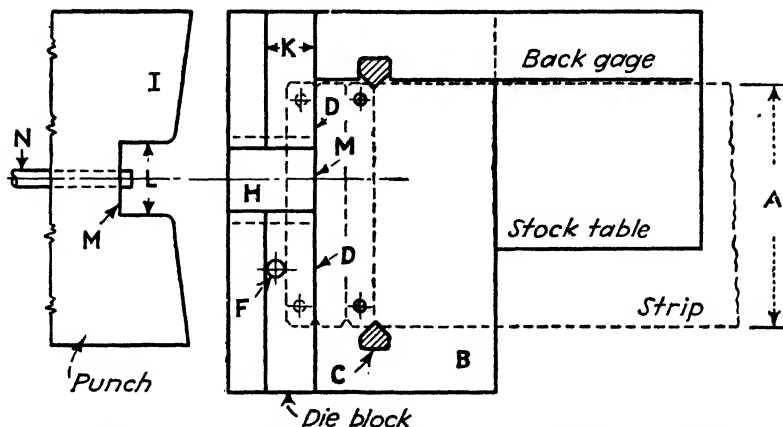
FIG. 228.—Automatic die for producing the terminal sketched in Fig. 227.

and the piece is cut from the strip on edges *M*. When the punch ascends, the pressure pad follows up until the pad face is normally flush with the die surface.

The finished work adheres within the punch opening and is ejected by the knockout rod *N*, near the top of press stroke. The pieces are
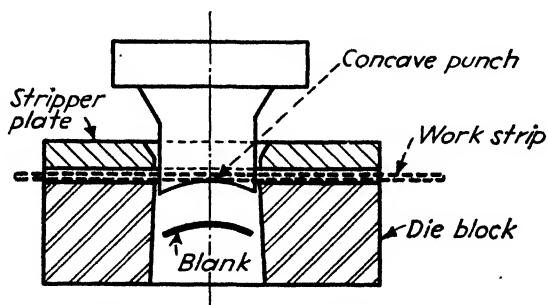
FIG. 229.—This die cuts a blank and curls it.

blown into a chute left of the press and are therefore prevented from falling on the die. Die set and guide pins are omitted to emphasize the tool operation. The view of punch *I* is a first-angle projection.

Forming and Blanking Simultaneously.—Figure 229 shows the method used in forming curved pieces while blanking them from a flat strip. The edges of a concave punch face, in descent, first shears

through the ends of the blank and starts curling it. The formed blank follows the contour of the punch, but the concavity of the punch is determined by trial to offset spring-back in the finished piece.

The same principle is applied in forming angles on the ends of blanks, as seen at *A*, in Fig. 230, or for shearing down the corners on a
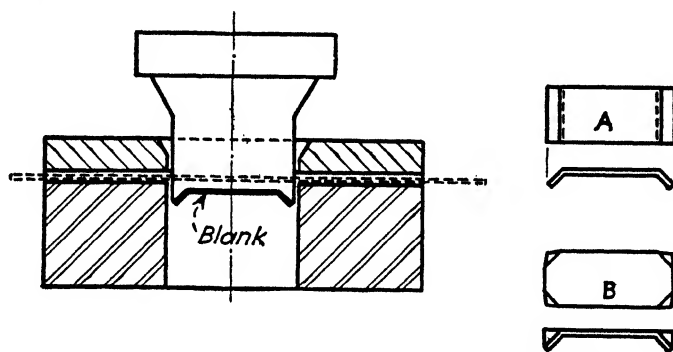
Fig. 230.—Forming down the ends while cutting a blank.

blank as at *B*. Holes can be pierced in the blanks at a first station. These dies do not produce accurate work, but the pieces are suitable for ordinary purposes. For producing accurate pieces of these types, an inverted compound die is used.

A round blank can be formed "dished" by using a convex punch face as shown in Fig. 231. Dished blanks are usually round but not
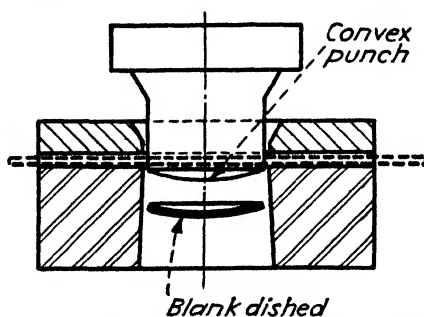
Fig. 231.—Blanking and dishing simultaneously.

necessarily so: they may be elliptical, square, or rectangular and still be dished. If a hole is pierced in a first station, it will distort slightly according to depth of the dish.

Forming and Ejecting with Vertical Side Cams.—Figure 232 represents two important principles in forming dies: forming slide *A*, operated by vertical side cam *B*; and horizontal ejector rod *C*, which removes the finished work *D*, by side cam *J* attached on the die shoe.

The ejector rod is square; it slides in a slot cut in spring pad *E* and is covered by a separate lower pad *F*. Tension spring *G* holds roller *H* in steady contact on side cam *J*, so that when the ram ascends, the ejector rod is advanced toward the right by a 45-deg. angle near the top. The work is carried up with the pad. The right end of the rod ejects the work by contacting its formed-over arm *K*.

'At the completion of punch descent, slide *A* has advanced and bent over arm *K*, on the work, on to a blade attached in the pad, as shown. Punch *L* contacts the slide and spanks the bend flat; the slide has a 1-deg. clearance angle for that purpose.
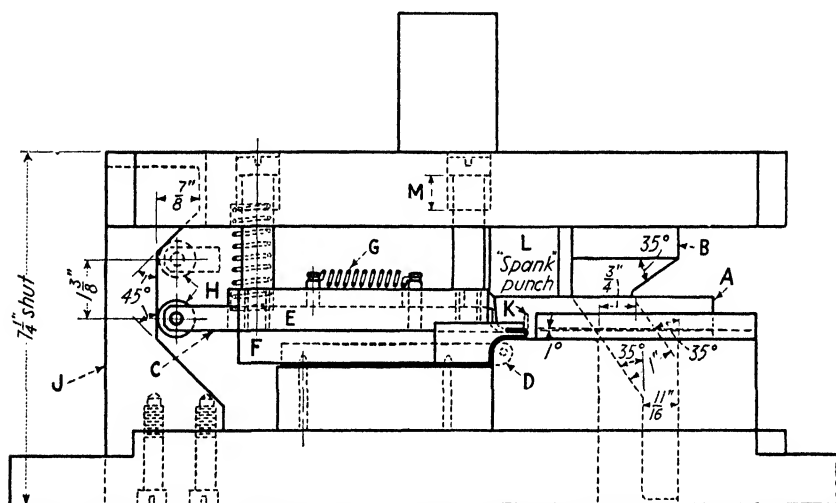
Fig. 232.—Vertical side cams are employed in forming, ejecting, and sometimes for trimming operations. The horizontal ejector rod *C* is operated when the ram ascends, by a roller in contact with vertical side cam *J*.

When vertical side cams are being designed, several factors enter the picture: (1) 35 deg. is the practical angle for easy movement and minimum wear on the slide. (2) Cam length must be sufficient to prevent its leaving the slot in the slide, at highest ascent, unless the slide is returned by a spring. (3) Dimensions $1\frac{1}{16}$, $\frac{3}{4}$, and 1 in. must allow the cam to ascend without interference. (4) The slide advance must not begin until the spring pad is seated in the work, in which dimension *M* is involved. (5) There must be sufficient slide travel to form over the part. A careful layout should be made to determine these factors. There are times when a faster or slower angle than 35 deg. must be used, and greater cam widths than those given under (3).

If a = angle on cam,
                    v = vertical descent,
                    h = horizontal travel of slide,

then

$$h = \tan a \times v \text{ and } v = \frac{h}{\tan a}.$$

When $a = 35$ deg.,

$$h = 0.7 \times v \quad \text{and} \quad v = \frac{h}{0.7}.$$

Care must be used in running most forming jobs to prevent a "doubleheader," as it is called. This means placing another blank in the die and tripping the press before removing the previous one. Most bending and forming dies are accident hazards, unless a chute is installed through which to introduce the blanks on the die. If this cannot be done, the job should be run in a press provided with safety devices, so that the press ram cannot be operated either by intention or by accident while another blank is being placed under the punch.

Inexpensive Bending and Embossing Die.—The shape and dimensions for a hot-rolled steel part, of which only 2,500 are needed, is
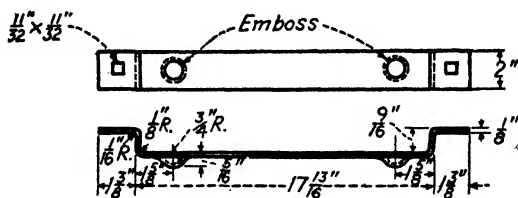
Fig. 233.—Low production for this part required the development of an inexpensive two-operation die.

shown in Fig. 233. No repeat orders are expected. The developed length of the blank is 21.414 in. The punch holder and die shoe are purchased without guide posts, and the tool is aligned in the press by using "setup pins" shown at diagonal corners of the die in Fig. 234.

In operation, the material strip is fed from the right-hand side of the tool. The strip is guided between two hardened backing-up heels A and under the cutting-off punch B, across the cutting-off edge C and then over spring pad D. The forward end of the strip finally stops at the extreme left end of the tool by contacting the 45-deg. angular block E. The angular block swerves the strip and causes it to register within the front stop block F. Backing-up heels are fitted against the right-hand side of the die-shoe slot and project $\frac{3}{8}$ in. above cutting edge C. These heels guide the cutting-off punch when the ram descends.

The strip is now in position for the first operation, namely, cutting off, bending the four angles, and embossing two circular indentations. Perforating the two square holes in the ends is performed at the second station. The press being tilted, the first-operation piece is easily pushed from the spring pad and into the second position, just off the pad and toward the rear of the tool.

For the second operation, the work is gaged endwise in a cleared opening $17^{13}\!/_{16}$ in. long, which is the distance between the two die blocks G. The work is retained in position by two short stop pins H.
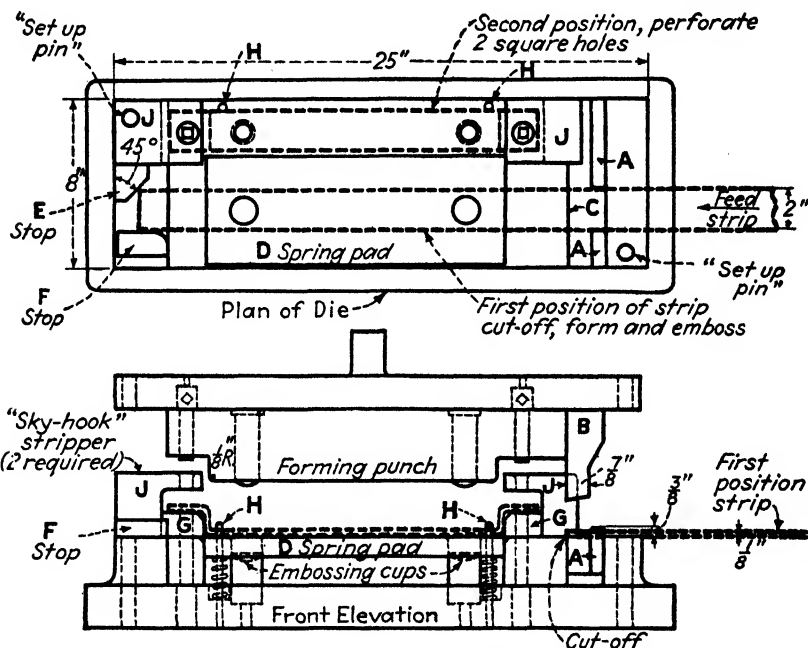
Fig. 234.—Cut-off and forming is done on a spring pad in a front station. The piece is then pushed back to the rear in the tilted tool, between blocks in a second station, for piercing the two square holes in the ends.

Perforating punches are stripped by two "sky hooks" J, when the ram ascends. These hooks are provided with considerable clearance spaces underneath them and are firmly attached to the die shoe. When the ram ascends, the work is carried up by the punches. When stripping occurs, the press inclination causes the work to slide off the die and to clear the short stop pins H. Finished pieces fall into a tote box placed behind the press.

Embossing and Piercing Holes for Screwheads.—Piercing and embossing a countersunk hole can be done in several ways. The hole can be pierced at one station. An embossing punch, with a pilot that

engages the pierced hole, is brought into action to emboss and spank the countersink at a subsequent station. However, this method usually distorts and enlarges the hole, because the hole is *pierced before* embossing the countersink.

Another method, given in Fig. 235, is used at one station. The pierced hole is not enlarged, because it is *pierced after* the countersink has been practically embossed. In operation a strong spring pad holds the strip, while the punch
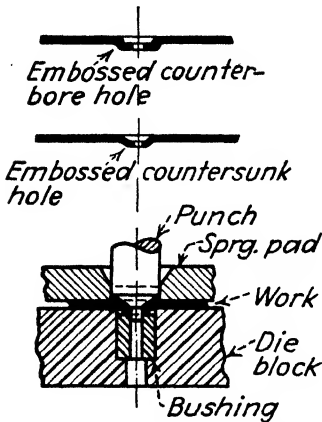
FIG. 235.—By this punch and die construction, the countersink in the work is practically embossed before the hole is pierced, thereby avoiding enlargement of the hole.
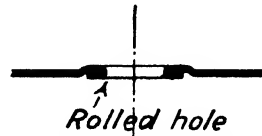
FIG. 236.—Insulation on wire or cable is prevented from being cut or worn when pulled through holes in apparatus if a rolled grommet hole is employed.

descends and embosses the countersunk portion of the strip down to the bushing face, where the hole is pierced. The punch, continuing in descent, spanks the countersunk portion of the metal around the piercing punch.

An embossed counterbore can be pierced and embossed as shown in Fig. 235, but the metal is likely
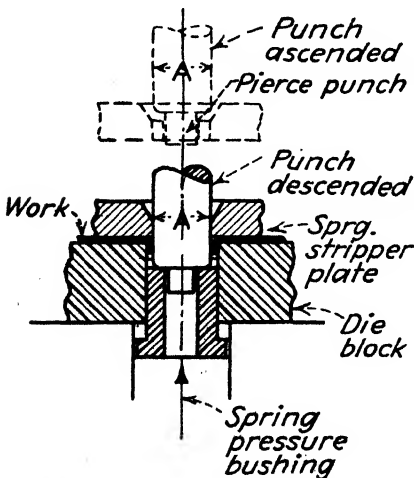
FIG. 237.—A rolled grommet hole is started by piercing and extruding a rim, using a single punch.
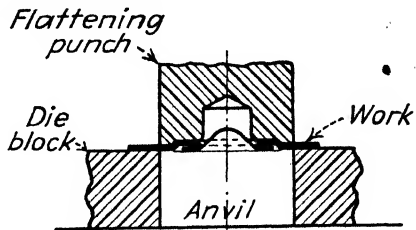
FIG. 238.—With the extrusion placed down on an anvil in the die the rim is rolled under and seamed as shown.

to be drawn away from the hole, because the hole is *pierced before* the counterbore has been fully embossed. If an enlarged hole is

objectionable, it is best to emboss the counterbore in a previous station that has an ejecting shedder.   In another station, pierce the hole on a bushing face below the die sur-
face, as shown in Fig. 235.   The bushing can be designed as a shedder to eject the work after piercing.

In sheet-metal thicknesses exceeding $\frac{3}{64}$ in., a pierced slug can be punched part way out, usually to a height of half the stock thickness.   These protrusions serve as dowels for locating another piece in apparatus assembly or for locating the piece itself on another part.   Two slugs are protruded for a double location of the part, and their diameters and center distances must fit the holes into which they are assembled.   The operation for protruding slugs has been illustrated and described under Fig. 86 in Chap. XI.

Fig. 239.—Dimensions for producing a fold over grommet hole $\frac{7}{16}$ in. in diameter in No. 22 U.S.G. steel.   The original hole is pierced 0.300 in. in diameter.

Folding over Grommet Holes.

The rolling and seaming of pierced holes, usually called a "rolled hole," is shown in Fig. 236.   It is a smooth hole with nicely rounded edges inside.   It is mostly used as an opening for conducting small cables.
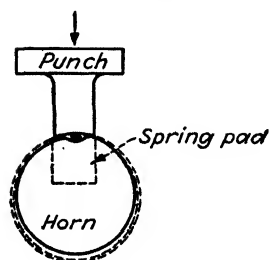
Fig. 240.—When work diameter permits, a spring pad is used in the horn for lock-seaming, and sometimes the hooks can be formed on the spring pad.

Rolled holes of $\frac{1}{4}$ in. diameter and up are done at two die stations (Figs. 237 and 238).   For rolled holes under $\frac{1}{4}$-in. diameter, three operations are generally required.   The hole is pierced in the first station, and the second and third operations are similar to those in Figs. 235 and 238.

In Fig. 237, the hole is cut by the pierce punch in descent, when it enters the spring-mounted die bushing.   Continuing in descent, the body diameter A of the punch extrudes the pierced hole as shown.   In the second operation the extrusion is rolled under and seamed against an anvil when the flattening punch descends, as shown in Fig. 238.

Figure 239 gives the dimensions used in practice for piercing, rolling, and folding a $\frac{7}{16}$-in. diameter grommet hole. This shows the relationship between operations.

Forming Locked Seams.—A variety of forming is performed in horn presses. For lock-seaming the bodies of pails, tubes, barrels, boxes, cans, drums, or spouts, a horizontal stud, or horn, is substituted for the table. The horn usually has a cross section similar to the opening in the work; however, the horn is smaller to facilitate work removal.

In lock-seaming operations, the opening in the work is placed over the horn, hooked seam up. The punch, in descent, flattens and locks the seam together. The narrow face of the punch is parallel with the horn and directly above it, as shown in Fig. 240. The work gages against a backstop on the horn.

Hooks for Locked Seams.—The principles involved in producing locked seams are presented in Fig. 241. End hooks on the blank for making the seam are plain bending operations. One hook must be bent *up*, and the other one *down*, as shown at *A*; both hooks are bent at a slight angle, to facilitate folding the seam.

Fig. 241.—Four steps in forming a locked seam.
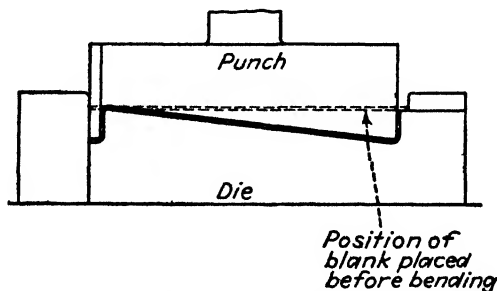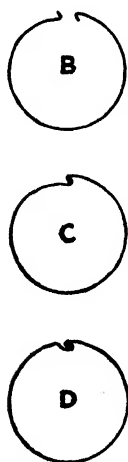
Fig. 242.—A good method for producing the hooked ends is by using a V-bender die.

If the material is light gage and the work is rather large, circle *B* can be formed by *hand*. If the material is too heavy for hand forming, the circling is done in dies. At *C*, the circle is shown hooked together by

hand. At *D*, the seam is completed, after it has been flattened and formed in a horning press die.

There are several ways to produce the hooked ends on the blank. It can be done in a "bar folder" or press brake. Probably the most satisfactory method is shown in the V-bender die (Fig. 242) in which the finished work is close section-lined. The lock seaming itself is performed with the hooked ends positioned over a plain horn.

CHAPTER XVIII

ASSEMBLING DIES

Most of the Single-station Assembling Operations Discussed Can Be Adapted for Use on Dial Feeds and Multiple-station Tools

In Many Cases It Is Easier to Feed Parts into Assembly Dies if the Tool Is Set Up in a Horizontal Press

Assembling Dies Are Composed of Five General Types: Press-fitting, Staking, Curling, Seaming, and Riveting. Each Type May Be Further Subdivided into Several Others.

Press-fit Assemblies.—An example of a press-fit assembly is that of forcing a shaft through a smaller hole in another part and to a depth controlled by a stop. Press-fitting assembly of a shaft to a gear, cam,
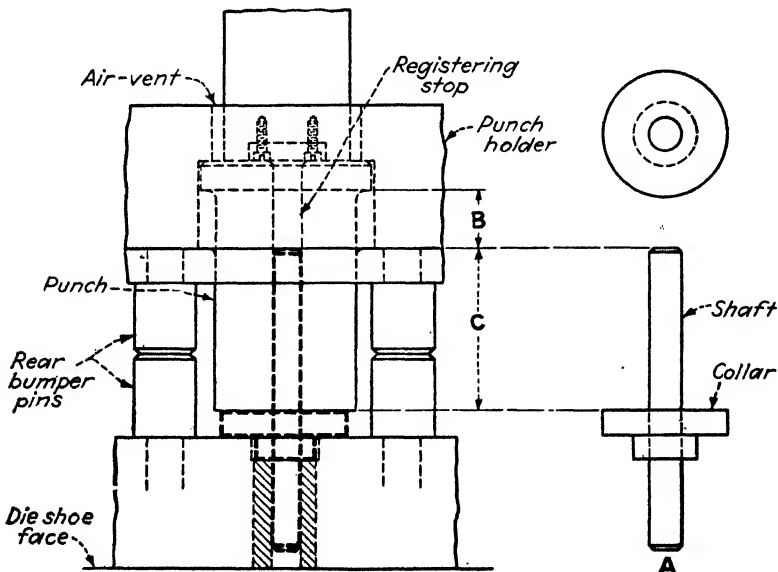
FIG. 243.—Bumper pins should be provided in press-fit assembly dies to check the descent of a worn press slide and to assist the die setter in adjusting the height of press stroke.

pawl, or collar is done as shown in *A* (Fig. 243). The hub on the collar is located in a counterbored opening in the die block. The punch has an easy sliding movement represented by the distance *B*. One end of

the shaft is inserted in the punch by moving the latter up; the opposite end is centered in the hole of the collar. The operator then permits the punch to slide down to align the shaft vertically.

When the ram descends, the shaft is pushed through the collar and into a clearance hole in the die, until the upper end of the shaft contacts the registering stop. Thus, distance C becomes a constant dimension in each assembly.

Ring Staking.—In ring staking, the metal is forced either *inward* or *outward* by plastic flow. When the cutting ring is greater than $\frac{1}{2}$ in.
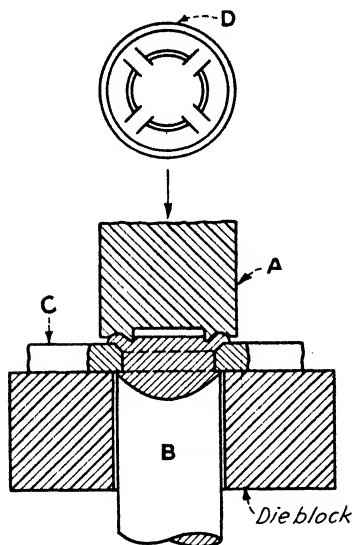
FIG. 244.—A four-segment staking ring has the cutting edge disposed to force the metal outward and into a countersunk hole.
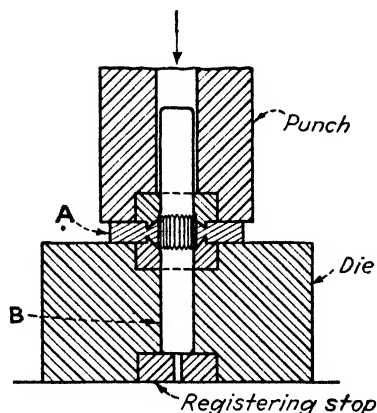
FIG. 245.—Metal around both sides of the hole in plate A is staked inward against the knurling on shaft B, by the action of a staking ring above and below the plate.

in diameter, the ring is divided into three or four equal segments to ease the pressure needed to establish plastic flow.

Punch A, in Fig. 244, has ring staked the end of the shouldered shaft B into a countersunk hole in plate C. The shaft rests below the die on an end support, not shown. In this case the side angle of the ring must force the metal *outward* and into the countersunk hole. The inside wall of the staking ring is vertical. The metal slightly overflows on to the plate. A first-angle view D of the punch face shows the ring divided into four equal segments to relieve the punch pressure. The cutting edge of the ring is a flat, about 0.005 in. wide, to prevent wear.

Figure 245 shows two staking rings.　Each ring is a press fit in the punch and die, respectively.　Both sides of the metal collar *A* are ring staked closely around the "straight-knurled" portion of shaft *B*.　The angular ring of each staking punch forces the metal *inward*, closing it tightly around the knurling.　Both staking rings are divided into four segments.

In "spot" staking, the operation is practically the same as just described, except that small angular points, at three or more equal spaces, are used in place of the ring.　Spot staking is sometimes necessary when securing metal materials on nonmetallic parts.

Nut Assembly.—By using a patented process hardened nuts are assembled through steel plates by using the nut itself for the perforat-
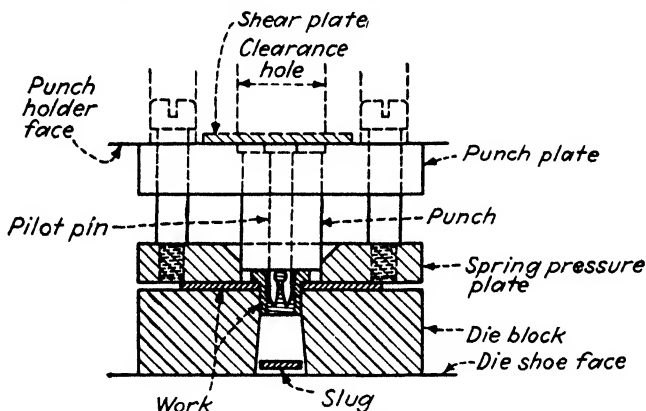
Fig. 246.—A hardened nut is assembled through a plate by using the nut itself as a perforating punch.

ing punch.　The die designs given in Figs. 246 and 247 illustrate the tooling details.

In Fig. 246 the die is shown closed, and the plate and nut assem-bled are closely section lined.　The plate is located between stops on the die.　These stops, not shown, position the plate so that the point where the nut is to be assembled lies over the die opening.　The tapped hole in the nut is placed over a four-pronged "spread" pilot pin, shown through the punch.　The die opening provides generous punch clearance for the body of the nut.

When the ram descends, the spring pressure plate first contacts and holds the work plate.　Then the punch forces the nut to perforate the plate.　The resulting slug falls through the die.　At completion of the press stroke, the shoulder on the nut registers against the surface of the work plate.　When the ram ascends, the pressure plate holds the work down until the pilot pin withdraws.

To prevent press damage if the nut is placed upside down, the punch is made to work against a shearing-off pin, or a shear plate, as shown. If the work is unintentionally reversed, large end down, the shear plate is cut through by the punch into a clearance hole above, as shown in Fig. 246.

An inverted die arrangement for the operation just described is shown in Fig. 247. The nut is placed over the pilot pin in the punch.
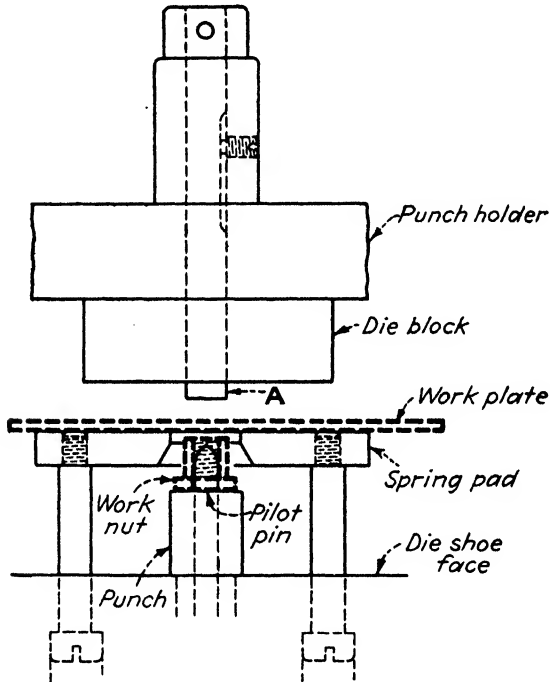
Fig. 247.—In this inverted die, the nut is assembled through a plate by forcing it to cut a slug into the die; knockout rod *A* ejects the slug at the top of the press stroke.

The tool is shown in open position; the ram, punch holder, and die are ready to descend and grip the work plate on the spring pad and, by continuing, depress the pad and force the nut through the plate.

Low-cost Spool Assembly.—A pair of swinging leaves provided with opposite V's is shown attached to a spool-assembly die in Fig. 248. The function of the leaves is to centralize and clamp the parts in alignment for assembly in an ordinary No. 2 punch press. The assembled spool is shown at *A*.

The swinging leaves are normally elevated by the coiled springs *B* that surrounded the two guide pins *C*. The leaves are centered when closed against the positive pin *D* driven through the die block *E*.

Height *F* of the leaves determines the wire winding space between the spool heads. A round die insert *G* contains three triangular staking points, equally spaced within the center hole. The depth of the center hole determines the projection of the core beyond the face of the assembled spool head. The punch, not shown, embodies a center hole of the same construction as described for *G*.

The first spool head is centered within a nest of four pins in the die block. The leaves are then closed; the core is next inserted and centered between the V's in the leaves; and finally the second fiber head is centered in a nest of four pins on the leaves. All three pieces are now in alignment. The leaves are held together by grasping
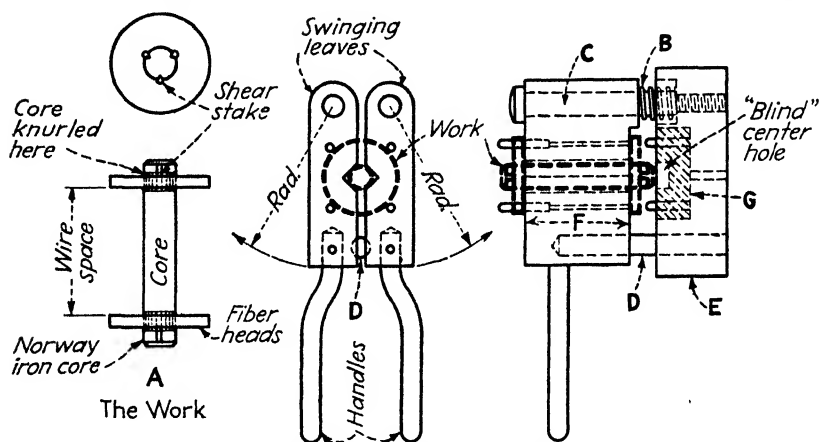
FIG. 248.—Two fiber spool heads are assembled and shear staked equidistant from the ends of the metal core, using a die with opposed swinging leaves for aligning the three parts.

the two handles or by a latch hook across them. Upon descent, the punch depresses the springs; pushes the three members of the spool frame together; and spaces, assembles, and shear stakes both heads simultaneously.

Spool assemblies are made at higher speeds in a special horizontal bench press. The core is placed in a horizontal sliding V-block of a length equal to the distance between heads. The V-block and core are located between the punch and die members. The punch-and-die construction for assembling and staking is similar to the tool just described under Fig. 248. Parts are fed to the die through chutes.

Riveting Dies.—Light riveting and staking operations can be done on a bench press or in a foot press. In riveting dies, pins or rivets are inserted through holes in the parts before placing them in the die. When a large number of pieces are involved, as in small rotor lamina-

tions, the pieces are stacked over pins in a separate plate, and the work together with the plate is placed in the assembly die. This method requires several assembly plates. The ends of the pins or rivets are then headed over by the punch and die. Staking at one end is done only when rivets with heads are used.

The staking edge is an angular ring section on the assembly plate under the rotor laminations. The diameter of the ring is the same as the circle of rivet centers. If both ends of pins are to be staked, the punch also carries a similar staking ring. If a twist is to be put into the armature laminations while riveting, pins that protrude from the punch engage in offset holes in the assembly plate and produce the twist during punch descent.

Curling dies are used for rolling over the ends of hollow rivets. The wall around the edge of the hole is stretched by the entrance of a curling punch; and as the punch descent continues, the edge of the rivet is forced to curl over on the surface of the part being assembled. Metal "eyes" are thus assembled through two or more pieces of metal, fiber, leather, and combinations of materials. Another function of curling dies is in the assembly of can covers, where the edge of a previously drawn cover is curled, crimped, or seamed around its edges, together with the body of the can or receptacle.

In seaming or clamping dies we have those assemblies where the sides or protruding lugs along the edges of a sheet-metal piece are closed or folded over and seamed on the surface of the part being assembled. In other cases the clamping lugs are sheared through one of the parts and into corresponding holes in another part and then folded down flat by the punch. This type of assembling is performed on small work in a multi-slide machine, shearing, piercing, inserting, and clamping together in one operation.

Forming, Assembling, and Seaming 125 Tubes a Minute.—The tube sketched in Fig. 249 is of 0.005-in. bright nickel ribbon. It is shown with the blank and the nine representations of die operations used in assembling and seaming the tubes. A schematic layout of the die is seen in Fig. 250. The die is designed for a No. 25 U.S. Multi-Slide Machine. A photographic reproduction of the machine appears in Chap. II. The die and machine completes one piece per stroke, or 125 per minute. One straight cutting-off blade and six cam-actuated forming slides are used in this setup. The slide movements are timed by circularly revolving cams.

The strip material is unwound from a horizontal roll by the pulling action of the feeding jaws in the machine. The strip, "edge up," first enters between two steel-wire guides, positioned horizontally

along each side of the center line of the strip. The strip then passes through a pair of vertical rolls, mounted within a small rectangular frame, not shown. The rolls, "male and female," are mated for rolling in two parallel beads in the strip, while it is being passed along. The wire guides extend up to the stationary cutting-off head K, through which the strip is passed by the feeding jaws.

On the right side of the head, the blank is cut off by the flat side cutter J, which is attached on the sliding bar Q and activated by a
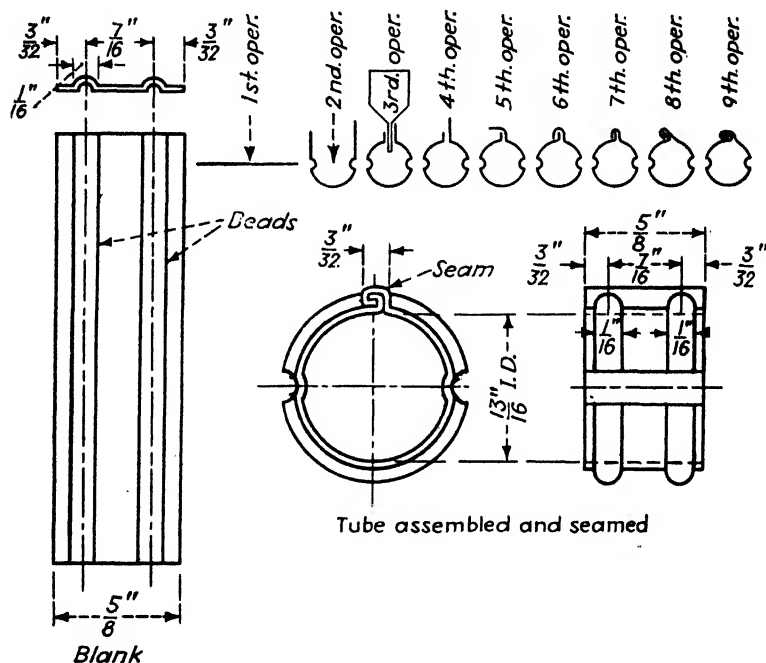
Fig. 249.—Nine operations in forming and seaming a tube made from the blank shown at left.

special cam on the front shaft. The feeding "throw" is adjusted to suit the developed length of the blank, which must be sufficient to form a circular tube $1\frac{3}{16}$ in. in diameter, plus an additional allowance for making the hooked-over seam for assembling the free ends.

The blank that makes the tube is fed tangent to the front side of the circular forming post G and is prevented from falling—when severed at J—by a spring-compression blade, or detent, P, shown at the center of the front forming slide A. Slide A is advanced just prior to the cutting-off operation, and thus the detent P holds the blank securely against the post. Severing the blank from the strip is the first die operation.

Two vertical grooves are seen in post G, diametrically opposite each other. In these grooves the vertical beads are indented in the tube by the advance of two small side punches H, mounted on right- and left-hand slides E and F. Previous to the advance of A, back slide B is brought forward until its positive offset blade N touches the rear side of the post, diametrically opposite detent P.

The concavity in front slide A when advanced forms the blank U-shape around the post (operation 2), and the simultaneous advance
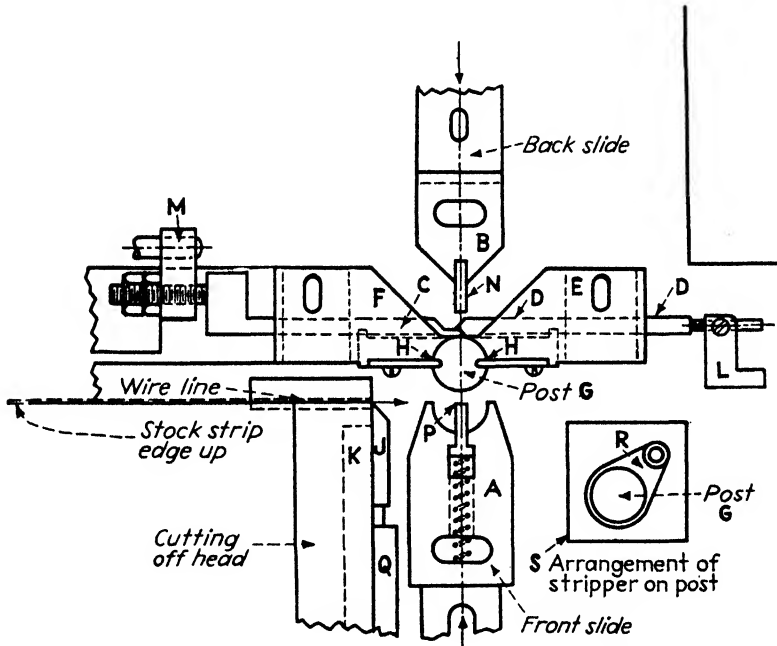
Fig. 250.—Plan of multi-slide machine tools for producing the bright nickel tube shown in Fig. 249.

of the right and left forming slides E and F completes the circle and contour of the tube (operation 3). Slides E and F are activated by the standard right and left cams furnished with the machine, while within E and F are the right and left seam forming slides D and C, controlled by auxiliary cams attached on the sides of the standard cams.

Slides D and C are advanced after E and F have completed the circle of the tube. E and F hold the work around the post while N is gradually withdrawn; D and C are then advanced and begin to form the "hooked" seam, as shown in operations 4 and 5. When D and C recede, N is advanced again and bends down half the seam,

as shown in operation 6; N is then withdrawn. Next in order, C and D are advanced again and pinch the seam together (operation 7) and then withdraw. Seaming punch D is then advanced alone and pushes the pinched seam at an angle toward the left (operation 8) and then withdraws. Member N is then advanced a third time and flattens the seam, thus completing the work (operation 9).

Following this juncture, all the slides have receded, and the vertical stripper R, which has been held above the work and which surrounds the post by a sliding fit, shown at S, descends and pushes the completed tube from the post. At the lower end of the post, at its center, a wire is attached which has a curved length that leads the tubes into a tote box. This layout shows that revolving cams and multiple slides can accomplish almost any desired mechanical movement, combination, and operation.

Latch Hook and Bar Ejector.—In assembling the yoke and stud, shown in Fig. 251, in the ring-staking die in Fig. 252, a positive and reliable ejecting device is necessary to lift the work with ram ascent.
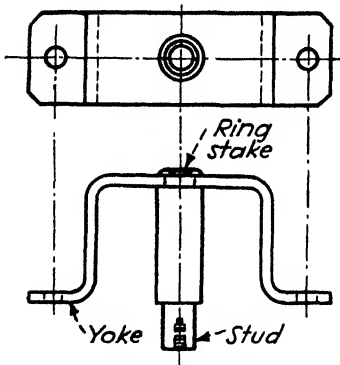
FIG. 251.—The finished work as assembled in the die shown in Fig. 252.

After ring staking in the downstroke, the ends of ejector bar A are engaged by the hooks; and in carrying the bar up, the centrally attached ejector pin B, directly under the work stud, is elevated and lifts the assembly from the die. In this design, work distortion is impossible, and positive ejection is certain.

When angles C, on the hooks, contact trip lugs D, near the top of the press stroke, the work has been lifted from the die; the hooks unlatch; bar A is released; and tension spring E lowers the ejector bar to its normal position.

Someone may remark that this operation could be done better in an inverted die in which a vertical knockout rod ejects the work. In analyzing this suggestion it is found that in reversing the position of the die and work, it becomes more difficult to insert the stud in the yoke than to place the yoke over the stud as in Fig. 252. A latch hook and ejector bar are found convenient in many types of assembling dies.

Assembling on Circular Dials.—Circular dial feeding is simply a development of the straight-slide principle of feeding work into dies.

The work is placed in a station, revolved, and finally assembled by a punch at one or more equally spaced stations. The number of possible working stations on a dial is directly proportional to the dial diameter.
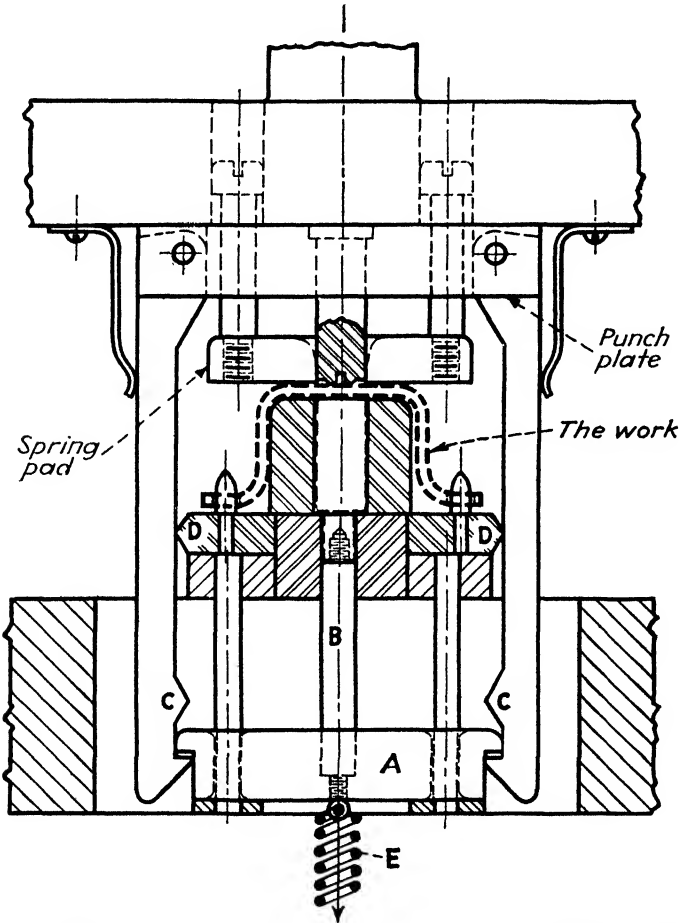
Fig. 252.—An assembly die in which the finished work is automatically ejected with latch hooks.

By using ordinary ingenuity, the variety of assemblies possible in dies equipped with rotating dials is surprising. Most of the single-station operations shown in this chapter can be arranged for feeding the work at stations on a revolving dial. The dial carries the loaded stations under the ram, where the parts are assembled in passing and halting, under the descent of one or more punches. Illustrations and descriptions of assembling dials appear under Figs. 51, 52, and 53.

Assemblies Made in Horning Presses.—In Chap. II will be found a reproduced photograph of a horning press. A great variety of assemblies are done in presses of this type. In some horning presses, the table, or bed, can be horizontally swung on hinges toward the front; this makes possible the insertion of odd and difficult shapes of work. The swinging table can also be raised or lowered to suit the shut height of dies. The lock seaming of circular drums in dies used in horning presses is described under Figs. 240 and 241.

Lock seaming is performed by the punch in descent, with the hooked-together ends positioned over a plain horn. When the diameter of the work is large enough to permit, the hooked ends are formed on a spring pad, as indicated by the dotted lines within the horn (Fig. 240). It is sometimes possible in using a spring pad to arrange the horn and "force," as the punch is called, so that the hooks can be formed on the horn. The ends are then hooked together, placed on the pad, and lock seamed by descent of the force.

Lock seaming of metal bodies of other cross-sectional shapes is similarly handled. In producing locked seams on a production basis, an automatic seamer bends the hooks and locks the seam in one strike. These principles are the first steps in the design of intricate automatic machinery for the continuous production of can bodies.

Assembling Centralized Work.—Figure 253 shows the extent to which practical centralizing devices can be successfully carried in assembling dies. The same principle can be applied in blanking, perforating, forming, drawing, and many other tools. Square, rectangular, round, oval, and many odd shapes of work can be automatically centralized or equalized before performing operations.*

In the schematic end view of the die (Fig. 253) at A, work plate B, which varies in width and length, is shown centralized over a die opening. Plate B must be centralized both ways, that is, in its width and length, before the actual assembling operation begins. The purpose is to assemble the hardened shouldered stud C centrally within the plate, by piercing it through at the center of the plate. The opposite edges of the plates are parallel, and the edges are square.

Pressure plate D carries four vertical pins E, of equal lengths. The free ends of the pins have slanting cuts of 45 deg. which slant toward each other, as shown. The short heights of the pins are normally flush with the surface of die block F, before the work plate B is placed between them.

* For a treatise on jig-and-fixture equalizing mechanisms, many of which can be used in dies, see the author's "Practical Designs for Drilling and Milling Tools," McGraw-Hill Book Company, Inc., New York.

In the plan view we have an example of the toggle-joint, or "lazy-tongs," principle for centralizing a piece of work endwise. The two clamping jaws G slide within channels H. The channels are secured on filler blocks each side of the die. Two links J, of equal lengths, are pivoted on G and terminate at a common pivoting point in block K. Block K is guided in T-slot L and at right angles to channels H.
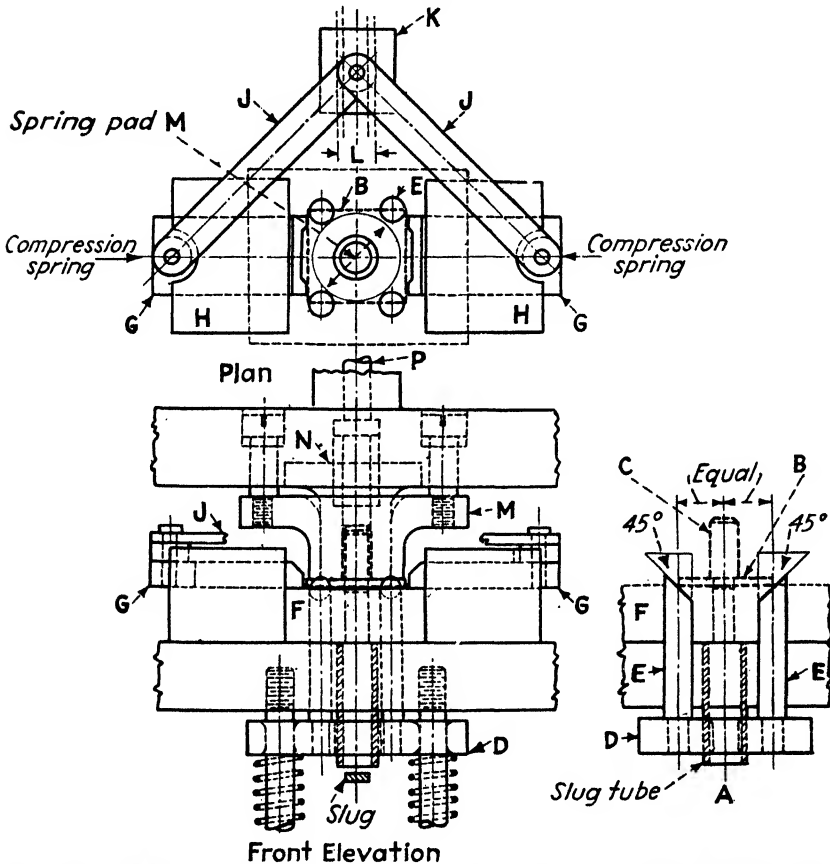
Fig. 253.—This die centralizes a rectangular work plate in two directions before the punch performs the assembling operation.

It is obvious that by this construction slot L will cause the jaws G to approach and recede equally when either jaw is moved toward the right or left. The clamping ends of these jaws are relieved by an entrance angle, part way down, as shown, and work plate B is placed between the jaws and over the angular faces on pins E. Thus the work becomes immediately centralized *endwise* between the jaws. When the ram descends, spring pad M contacts the work plate ahead

of punch N and, continuing down, "levels" the plate over the angles on pins E and then carries it flat down on the die face.   The work plate is now centralized in reference to both its width and length over the die opening.

FIG. 254.—Two sheet-metal pieces, both blanked and formed in progressive dies, are assembled and clamped together at C, by the "side-cam die" in Fig. 255.

Stud C, having previously been inserted in the punch and held there while the die is open by a side compression button, descends with the punch and pierces through the center of the work plate.   The

FIG. 255.—A typical assembling die in which two pieces are united by using horizontal slides H, operated by vertical side cams.

pierced slug falls through the die and slug tube, as seen in the front elevation.   The registry of the shouldered knockout rod P in the punch holder forces the shoulder on C against the face of the work

plate. The distance between the punch face and the extreme height of the knockout rod is 0.005 in. *less* than the average lengths of the work-stud bodies. This allowance covers the tolerance variations in the lengths of the studs.

Clamping Parts together in Side-cam Dies.—Figure 254 represents a typical assembly of parts produced in dies such as are illustrated in Fig. 255. This die is representative of a large variety of press tools in which assembling, clamping, seaming, bending, and trimming can be performed with horizontal slides activated by vertical side cams.

The features in this die are block *D*, in the angle of which work *B* is located on two pins, and snap button *E* which positions and holds the piece. Piece *A* is pushed up into slots in both sides of punch *F*. It is held there by friction of its two wings which "hug" the punch. Pieces *A* and *B* are thus located, one on the die, the other on the punch, in proper alignment for successful assembly when the punch descends.

When the upper piece descends with the punch, its flange enters between the upturned claws on the lower piece; spring *G* is compressed; slides *H* advance and bend over the claws on to the flange. Approaching the low point in ram descent, the punch spanks the noses of the slides, thus forcing the claws to hug the flange tightly. In the upstroke, the slides withdraw, and push-off pin *J* strips off the work that remains standing on the die.

It is good practice in all side-cam bending dies to spank the slides over the work to give the piece a definite set; the slides are constructed with a slight vertical clearance for that purpose. They are caused to withdraw by compression spring *K*.

CHAPTER XIX

COINING, SWAGING, COLD-SIZING, AND EXTRUDING

These Press Operations Induce Displacement of Metals by Plastic Flow and Therefore Require Extremely High Pressures

Introduction.—Extra-heavy presses and dies are necessary for swaging, coining, extruding, and cold-sizing operations. Die bodies must be above average sizes and be constructed of high-strength materials to resist unusual stresses. The presses employed are four types: knuckle joint, eccentric shaft, percussion, and hydraulic, depending on the work size and the time interval allowed for the operation. Knuckle-joint presses inherently have short powerful strokes but do not provide sufficient dwell at the bottom of the stroke, which is available in the hydraulic type. Therefore, the latter may be used for work having deep extrusions or for large cold-sizing or pressing jobs, where the extra dwell can be utilized to put a definite set in the work. Swaged and cold-sized parts are highly compressed. Consequently, the metal becomes harder and more dense, and the resistance to wear may be increased as much as 80 per cent over machined parts.

Types of swaging dies are (1) progressive swage and cut-off; (2) swaging parts with a peripherical "draft" for hand removal of the work; (3) swaging with an overflow flange which is subsequently trimmed; and (4) confined swaging, or coining, in which the part is completed from a blank having about the same volume as the finished piece. In the last two, a positive ejector is necessary to lift the work from the die in connection with ram ascent.

The simplest swaging operation is to flatten a space on small annealed rods at a first station and then to cut off to length at a second station. But progressive swaging dies are unreliable for producing accurate work with pierced holes, because swaging lengthens the stock. In all swaging and cold-sizing dies it is important to provide positive stops, or spacing blocks, between the upper and lower dies. These positive stops establish the lowest point in ram descent and determine the thickness of finished work.

Before designing the press tool, it is best to make experimental swaging dies and to try them between planishing blocks in a press. This test will determine whether or not the proposed operation is practical.

Die Steels for High-pressure Operations.—Before entering the subject of the designs for cold-forging and swaging dies, it is best to consider some of the steels employed in tool construction. Success of the tool often depends upon the right selection of die steels. The raw-material cost for dies is only about 5 per cent of the total, whereas 95 per cent represents labor. This shows that a premature failure of the tool, because of using the wrong steel, is a costly experiment and may be further increased by disappointing delays in production.

Die Steels for Cold Forging and Swaging.*—Cold-forging or sizing dies are subjected to severe punishment due to the enormous pressures exerted on the work. This is especially true when cold forging very intricate outlines such as gears and irregular cams.

For cold-forging dies, the following two types of steels are widely used.

Type 1.—This is a chrome-tungsten oil-hardening steel combining high hardness and maximum toughness. It is a steel easy to machine and will lend itself readily to hobbing and broaching. Where dies have intricate shapes, this method of machining is a very economical way to make duplicate dies. Roughing out the die by using a template in a Keller machine is also a good method.

This steel, being an oil-hardening variety, distorts very little in hardening, and the heat treatment is rather simple. At 58 Rockwell C, this steel has high resistance to deformation and at the same time great resistance to shock. When properly hardened, the presence of tungsten and vanadium carbides gives this material high resistance to abrasive wear, which is of great importance in cold-forging dies.

It is this type of steel that has made it economically practical to do many of the more severe cold-forging operations, formerly considered impossible. Today it is common to see parts, formerly made in the drop-forge shop and of necessity entirely machined, transferred to the cold-forging department.

Type 2.—Where the die design is not too intricate and maximum wear resistance can be taken advantage of, type 2, known as the "air-hardening type" high-carbon high-chrome steel, has given a very good account of itself. This steel, however, is more difficult to machine and does not have such good shock resistance as type 1.

Heat-treatment of Cold-forging Dies.—Since no tool is any better than the kind of heat-treatment it receives, this subject is important. However, the story is too long and complicated by too many individual opinions to discuss in a treatise on pressworking of metals. Steel hardening and tempering are specialties; and since most diemakers

* W. A. Olsen of SKF Steels, Inc., in *The Modern Industrial Press.*

send out their work for expert hardening, there is very little trouble from this source. Those who desire detailed information on hardening and tempering should consult the A.S.M.E. "Handbook" or A.S.T.M. bulletins. These are available at technical libraries.

Cold-forging Precision Sizes.—The presses and cold headers are by far the most popular, as they offer maximum pressures at the critical moment of a controlled stroke. They are found in use on most of the general close-tolerance cold-forging work.

Finer and sharper details in minute cavities can be accomplished better with the hammers, and they are more frequently used in the manufacturing of silverware and jewelry.

As to die design, it is interesting to note that an article by D. H. Chason dealing with cold-swaging dies for steel parts was published as early as Feb. 22, 1912 (*American Machinist*), and contained principles that are today considered by many as basic standards in this field. Many new developments have come about since then, in regard to both die designing and processing.

Swaging Copper Terminals.—In Fig. 256 a pair of die blocks is shown for producing the soft-copper terminal in Fig. 257. The blank
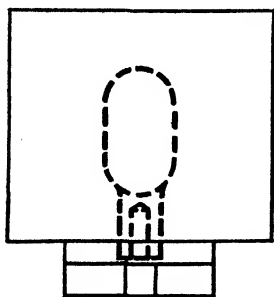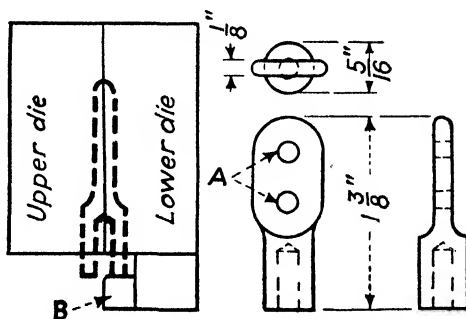
Fig. 256.   Fig. 257.

Figs. 256, 257.—To release work from the dies, the swaged portion of this soft-copper terminal has a semicircular edge to obtain draft.

is prepared by drilling one end and cutting to length. After swaging to shape, the holes *A* are pierced in another tool placed next to the swaging die. Stop *B* locates the blank endwise in the lower die.

Swaging with an Overflow.—Swaging with properly designed tools is probably the best method for producing small intricate parts in multiple uniformity. However, without some previous knowledge of swaging or experience that has shown the designer what can be done and what cannot, the final results may amount to nothing more than a bad headache. If there is any question as to the practicability

of swaging a given piece of work, it is best to use tentative dies for predetermining whether or not swaging will be successful.

Swaged parts have a distinct advantage over those made by any other method.   The pieces are much stronger, are practically wear-proof, have unusually bright smooth finishes, and are free of scales and burrs.   Many difficult designs of work are impossible to produce except by swaging.   A case in point is the steel gear (Fig. 258), shown as it came from the overflow swaging die (Fig. 259).

The flange, or web, *B* behind the gear is integral with the teeth. Flange thickness is determined by the overflow space *B* between the closed dies.   The flange is subsequently trimmed in a second-operation die; trimming coincides with the outside diameter of the gear.   The part could be trimmed larger in diameter, if the overflow flange were swaged greater in area.   It could be trimmed with a higher step of teeth, producing a cluster gear.   These variations indicate the possibilities in the design of swaged parts.

A typical die layout for swaging and ejecting small work is shown in Fig. 259.   The dead-soft steel blank has a diameter slightly less than the root diameter of the gear-teeth.   The hole diameter is an easy fit over the vertical center stud in the lower die.

FIG. 258.—Small parts that must resist wear, such as this business-machine gear with the integral flange behind the teeth, are swaged by the overflow process, and the flange is subsequently trimmed.

Height of the blank is determined by the volume of material needed to swage the piece and is easily found by experimental blocks during the initial trials.

The lower die opening is of internal-gear shape and is broached and lapped to size.   Shedder *C* is a sliding fit within the lower die; it registers in the die shoe at the closed height of the tool and at sufficient depth for swaging the thickness of the gear teeth.   The tool is operated in a 200-ton knuckle-joint press, which is several times the necessary capacity to swage the piece.

When the press is open, the hole in the blank is placed over the vertical stud in the lower die.   In descent, the ram squeezes the blank

between the upper and lower dies until plastic flow begins. Continuing the squeeze, the metal is forced to "flow" into all the interstices of the die. The hole in the blank closes tightly around the central pin; the gear teeth are formed; and the tooth thickness is determined by the registration of the shedder in the die shoe. Surplus metal overflows into space *B*.

Work ejection occurs near the top of the ram ascent. Heads of screws *D* contact the bottoms of hollow adjusting nuts *E*. The screws are attached to the ejector bar and elevate it as the ram ascends. When the shedder is flush with the lower die face, the work is
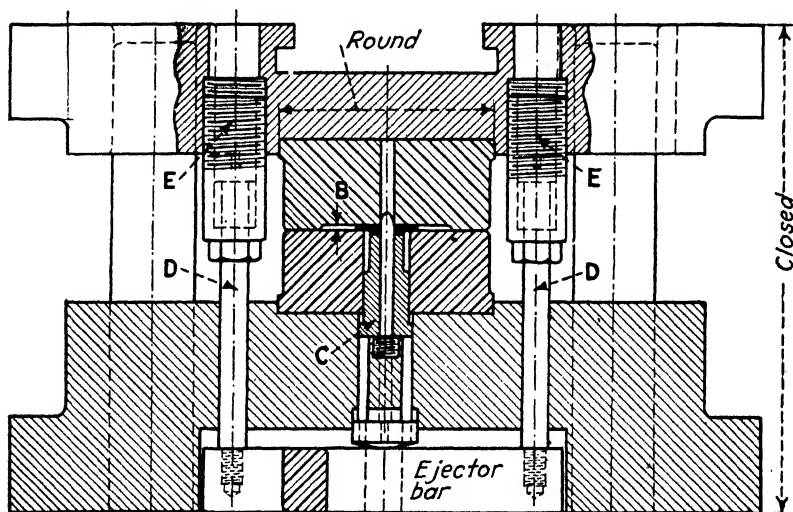
Fig. 259.—Tooth thickness of the swaged gear is determined by the registration of shedder *C* in the die shoe, and the flange thickness by space *B*.

ejected. The center pin is slightly tapered towards its point to aid ejection. All interior surfaces of the dies are smoothly polished.

Swaging dies cannot be used until thoroughly cleaned with gasoline and perfectly dry. If a small portion of oil remains in the die it will cause trouble when attempting to swage; it may fracture some part of the tool.

Coining Dies.—Coining is a high-tonnage operation. Under hundreds of tons pressure, the die forces metal by plastic flow into various embossed designs of raised panels, beads, depressions, ornamental outlines, and sharp corners. Coining dies include not only the mintage of money, medals, medallions, and jewelry parts but also the forming and embossing of buttons, locks, ornamental hardware, designation plates, and escutcheons.

A die in which the coining principle predominates is represented by Fig. 260.   The operation consists of drawing, forming, and coining the

Plan of punch and stripper
plate mounted on die shoe

Section A-A
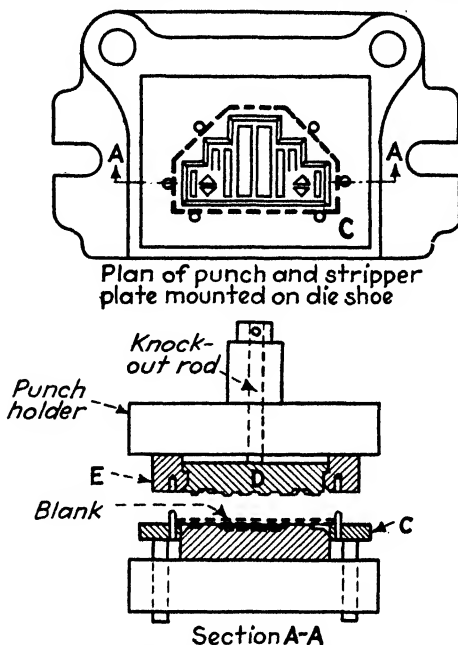
FIG. 260.—Shedder *D* also acts as the coining punch in this inverted die, which forms, draws, and coins an escutcheon plate.

ornamental escutcheon plate, one-half of which is shown in Fig. 261. The die is an inverted type to secure easy delivery of the finished piece by the action of a vertical knockout rod.

The punch is surrounded by the stripper pad *C*, upon which the blank is located within a nest of pins.   The pad is operated by the large vertical pins that rest on a heavy spring plate in the bolster.   The upper coining punch is shedder *D*, and it is a sliding fit within the outer drawing and forming die *E*.   The shedder is backed by coiled springs and in addition is operated by a knockout rod. When the ram ascends after completing the operation, spring pad *C* follows and raises the finished work from the lower punch.   The

Section
B-B

FIG. 261.—Sides of the raised portions of this escutcheon plate are squeezed thinner than the rest of the part to provide metal needed to coin sharp corners.

work adheres within die *E*, which carries it up to a point where the knockout rod depresses the shedder and delivers the piece.

The operation requires a pressure of 150 tons. This apparently excessive tonnage is necessary for coining sharp edges along the raised portions of the work, a section of which is shown at *B-B* in Fig. 261. The metal is squeezed thinner on the sides of the raised portions, and these sides are the source of extra metal for producing sharp corners.

Twelve right-angled beveled corners in the outline are *drawn*, while the straight sides between the corners are being formed down. The attached flange around the work perimeter is subsequently removed in a second-operation trimming die.
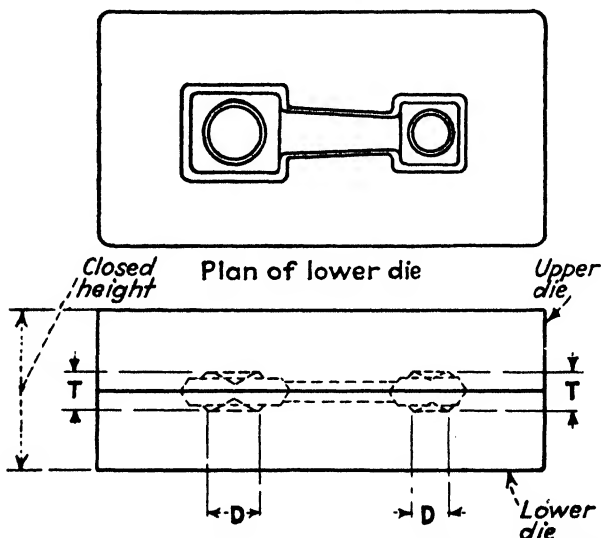
FIG. 262.—Forged bosses of comparatively large diameters are prepared with an impressed center relief for cold sizing. This precaution prevents pyramiding metal toward the center of the boss and avoids raising a slight hump at the center. The relief centers are exaggerated in the sketch.

Cold Sizing.—In recent years someone discovered that bosses could be cold sized by pressing as well as by machining, if the pressures were heavy enough. Figure 262 shows the die blocks and the principle used in cold sizing four bosses on a forged-steel connecting rod. To avoid using excessive pressures the dies are relieved, and a "draft" is provided along all edges of the work that are not squeezed to size. There is also a 45-deg. draft around the bosses to be sized, to facilitate removal of the finished work.

The closed height of the dies is checked by the surfaces of the blocks. These surfaces are in a plane coinciding with the longitudinal center plane of the work. Areas of the stop surfaces should be large enough to withstand three times the yield strength of the metal being sized.

The check determines the thickness to be sized, or dimensions T. Bosses D are also squeezed to size.

Certain heavy-gage sheet-metal blanks are cold sized to produce uniformly rounded edges and planished surfaces and for other corrective purposes. Small work to be sized in thickness is usually milled about $\frac{1}{32}$ in. oversize, and larger work to half this amount. The dies used are similar in principle to the one described under Fig. 262 and descend to a sizing stop either on the die surfaces or on spacer blocks. It is good practice to select a knuckle-joint press having a factor of safety of three or more over the maximum work pressure.

A practical determination of the necessary pressure for cold sizing is to squeeze the first pieces with the dies placed in a hydraulic press provided with tonnage gages. The mathematical computation depends on

$$P = \frac{A \times S}{2,000},$$

where P = pressure required in tons.

A = area to be sized in square inches.

S = ultimate compressive strength of the work material per square inch.

Designing Cold-sizing Dies.—The art of successful cold sizing, or "cold forging," as it is sometimes called, depends upon four conditions.* (1) Flow of the metal must be carefully planned to avoid local areas of excessive stresses. (2) Maximum local stresses must be safely within the strength of available die steels. (3) The die members must be built up in a sufficiently rigid manner to give proper support to the working die steels. (4) The press selection must be made with proper consideration for metal yield point (see Fig. 263), the effect of restraint of metal flow, pressure on contact blocks, time allowances, and rigidity requirements.

FIG. 263.—This chart shows the yield point of commercially annealed steel of various carbon contents.

Developments in all four of these classifications have greatly increased the practical range of cold-sizing operations.

* E. W. Bliss Co.

Sizing, instead of machining, is an increasingly popular method of smoothing contact surfaces and squeezing bosses, etc., to accurate dimensions at great savings in cost. The method is largely used on drop forgings, rolled forgings, malleable castings, steel castings, and nonferrous castings. Cold squeezing greatly improves the surface hardness and wearing qualities of the parts operated upon. Dimensional tolerances are affected by the rough size and properties of the slug. Variations in these are controlled by the use of sizing blocks or distance pieces in properly backed-up dies and properly selected presses. Hardened tool steels and their backing members yield elastically under high loads involved, and this must be considered.

Drop-hammer Presses.—Jewelry manufacturers use a drop-hammer press, usually called a "drop press," for light draws and coining. Some of these presses operate up to the equivalent of a 400-ton knuckle-joint press. They consist primarily of a massive bed and a guided weight which is lifted and then dropped in a heavy blow on the work in the die. Shallow draws, such as cigarette cases, are stamped in various designs in these presses.

Computing Cold-sizing Dies.*—Let us take a hypothetical job and figure the press capacity required. First of all, although we have endeavored to reduce the unpredictables as much as possible, there still is no substitute for experience and common sense. Care should be exercised in all cases.

Let us assume that we have a steel drop forging to be sized to limits of ±0.001 in. Its area, top and bottom, is 2 sq. in., and its carbon content is 20 to 30 points carbon. We first must find its yield point, which will depend on the carbon content and the state (whether annealed or partially cold worked). The majority of drop forgings are forged hot enough so that they are annealed upon cooling. Therefore, let us say that it is annealed.

By the chart (Fig. 263) we find that the yield point of commercially annealed steel, of 30 points carbon (always take the high value), is about 50,000 lb. per square inch, or 25 tons. In cases where this information is not readily available, it is advisable to run a compression test of the material to find its initial yield point.

The second step requires experience to determine how much to allow for pyramiding of pressures and restraint of metal flow. In our case, the area being sized is 2 sq. in.; the limits of ±0.001 in. are very exacting; and, further, the fact is that the area is not relieved by an impressed hollow. We should add 15,000 lb. per square inch, giving

* Courtesy V. R. Parker, M.E., E. W. Bliss Co., in *The Modern Industrial Press.*

us a probable average yield point due to pyramiding of pressures and restraint of metal flow of 65,000 lb. per square inch.

To obtain the job requirement, the area in square inches is multiplied by the probable yield point, which in our case is 2 sq. in. $\times$ 65,000 lb. per square inch, giving us a total of 130,000 lb., or 65 tons.
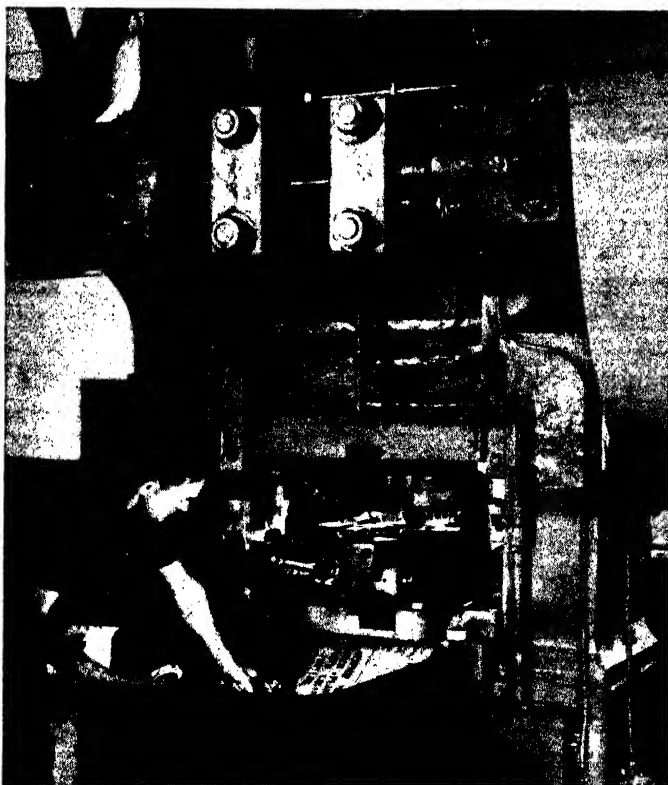
Fig. 264.—A large knuckle-joint press producing cold-sized connecting-rod bosses in a die similar in design to Fig. 262. The pieces are fed through a chute at the front of the press and removed at the rear, as shown. (*Courtesy of E. W. Bliss Co.*)

The next step is to obtain the area of .the size blocks to be used. This is generally determined by the accuracy desired and the variations anticipated in the piece to be sized. In our case the limits are very close, ± 0.001 in., and we can expect about a $\frac{1}{16}$ in. variation in the dropforged piece that we are sizing. The practice for such conditions is to use a constant of 3. This constant multiplied by the job requirement of 65 tons gives us 195 tons to be taken by the size blocks. The pressure per square inch to be carried by the size blocks must be very

low, because the fatigue yield point of any metal is very much lower than the normal yield point. Although the normal yield point of a tool steel for size blocks is in the neighborhood of 100 tons per square inch, to allow for fatigue, we shall place only 10 tons per square inch on the size blocks. Thus 195 tons total load divided by 10 tons will give us an area for the size blocks of 19½ sq. in.

With the job pressure figured at 65 tons and the pressure on the size blocks at 195 tons, the press should have a tonnage rating of their sum of 260 tons. To this may be added a safety factor if desired, to give an added measure of safety. In some cases warming up the piece to be sized, under the scaling temperature, will reduce the power requirements considerably; but there is always the risk of having a cold blank.

Scope of Cold-sizing Operations.—Besides the bosses on automobile connecting rods, those on the emergency-brake lever and steering-rod knuckles and even cast-iron piston rings have been cold-sized, and so have many other parts. As explained in bending and forming dies, there is in the work an inevitable spring-back which is sometimes difficult to control. In cold sizing, spring-back may be due to other causes than residual elasticity of the work material. It may be caused by elasticity in the die blocks, press frame, and bolster.

Extruding Aluminum Shells.—The tools and process for the cold extruding of soft aluminum shells, compared with drawing them, are relatively simple. Figure 265 illustrates the die principle for extruding an aluminum blank and producing a shell.

The punch is shown in three of its operating positions. At *A* the blank has been placed on knockout pad *D* in the bottom of the die, while the punch is up. At *B* the punch in descent has contacted the blank, and its impact increases the temperature of the material. Continuing in descent, the punch forces the metal into a plastic state and causes it to rise and fill the space between the punch and die. At *C* the punch is carrying up the finished shell, followed by the knockout pad. The knockout pad is operated by a cam underneath the press, as described previously under Fig. 23. The shell is stripped from the punch by contact under the positive plate *E*. The entering end of the punch is slightly smaller in diameter than across its top to facilitate stripping. An air-vent hole through the punch cannot be used; the metal would flow into it. Because of taper on the punch, a vent hole to facilitate stripping is not necessary. Shells are removed from the press by a jet of air.

Blank thickness and length of press stroke control the shell height. The limit is approximately seven times the shell diameter, depending,

of course, on the diameter and ductility of the material. The thickness at the closed end of shells is determined by the depth at which the punch enters the die, while the shape of the closed end is determined by the cross-section design of the tool members. The cross-section contour of the shell body can be any desired shape, if made uniform throughout its length.

The usual extruding press has a compact double-sized frame similar to the conventional straight-side presses. It is built with either single or double gears which impart slow speed and great power to the punch travel. It has a crank stroke, and the largest presses require a motor
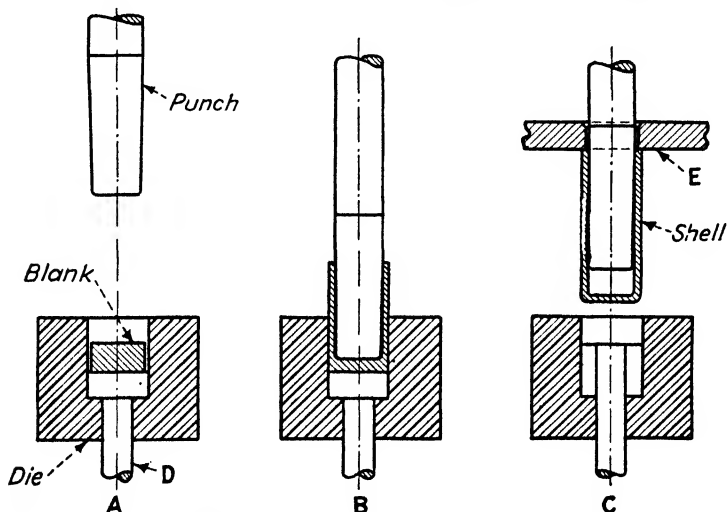
Fig. 265.—Aluminum is extruded from a blank laid in the die recess; when the ram descends, the metal squirts up around the punch and forms a shell.

of 50 hp. By hand feeding, a possible output for small shells is about 2,000 per hour. With an automatic feed, this output may be doubled.

Extruding Collapsible Tubes.—This operation is similar to extruding aluminum shells, but the press construction is different, and the hourly output is only half as great. Collapsible-tube presses are built both vertical and horizontal. The vertical machines belong in the arch- and pillar-press classes. All of them are back geared for a slow and powerful travel of the punch. The operating mechanism is a knuckle joint which imparts to the punch that smooth and easy action so necessary in producing collapsible tubes used for dentifrices, shaving creams, pastes, artist's tints, etc.

These presses are built in three sizes, 30, 60, and 130 tons capacities. The press strokes are from 4 to 4½ in.; the diameters of tubes are ¾, 1¼, and 2 in.; and the lengths are 6 in.

In operation, a tin- or lead-alloyed blank or disk is placed in the die, and a swinging arm automatically carries the punch directly over the blank. The ram in descent forces the metal up around the punch, as shown in Fig. 265. The punch is slightly tapered above its end to facilitate a subsequent removal of the work. When the punch ascends, the die knockout gradually raises the tube from the die, so that the tube clings on the punch. As the ram continues to ascend, the punch is automatically swung outward into a convenient position for removing the work by hand.

The Scope of Impact Extruding Operations.—Many parts ordinarily designed for drawing, spinning, stamping, or turning may be changed
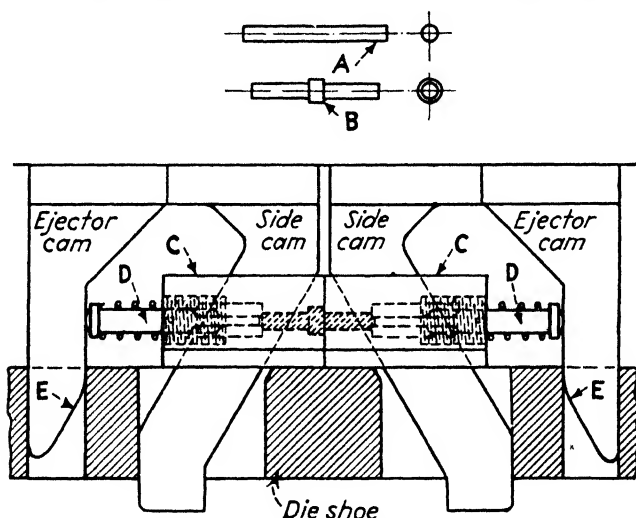
Fig. 266.—A squeezing die operated by side cams, which swages shoulder B on blank A. The work is forced out of the dies by the ascent of the side cams which force in pins D against the ejector cams.

in design to take advantage of the benefits of the impact extrusion process. Tool engineers and production superintendents are quick to see its possibilities. The fundamental advantages are close tolerances, dependable uniformity, high mechanical properties, and very low production costs.

Swaging Annular Shoulders.—The schematic design of a side-cam die in Fig. 266 illustrates the principle of cold swaging the blank A, with a shoulder as shown at B. A section through the shoulder may be of any contour—triangular, square, hexagonal, or round, as shown. The die is sketched in its closed position.

This is an easy application of the plastic-flow principle. The foremost design precaution is not to attempt an operation of this kind if

the unsupported length of the piece is more than $1\frac{1}{2}$ times its diameter when swaging begins. This rule may be exceeded slightly if the material is nonferrous, well annealed, and very ductile.

When the ram descends, the side cams force die blocks C together and swage the shoulder. When the ram ascends, the cams cause the die blocks to open, and the ejector cams clear the work from the dies by means of thrust pins D. When points E, on the ejector cams, in ascent, pass the heads on D, the ejector pins recede, because of compression springs; the work is released and rolls out of the die; and the blocks are fully opened for inserting the next blank.

These dies are sometimes designed to work in a vertical position. This will eliminate the expense of making side cams, but upper and lower ejector rods will still be needed. Dies of this character are usually designed as shown in the sketch, because loading the tool is faster, and ejection is more certain.

CHAPTER XX

DRAWING DIES

Specific Faults in Shells Can Be Traced to Incorrect Punch and Die Radii, Poor Blank-holder Action, Lack of Annealing, and Too Fast Punch Speeds

These and Other Circumstances May Cause Wrinkles, Cracks, Thin Spots, and Torn Shells

Introduction.—The drawing of shells from sheet-metal blanks seems to have been one of the unnoticed events following the American Civil War. The records reveal that a patent was issued to J. H. Cole, a Millbury, Mass., inventor, who described a new and useful punching tool that could force cold metal blanks to "flow" into the shapes of cups, ferrules, and the like. Cole sold his invention to a local millwright J. J. Parker, who in 1869 established the Parker Ferrule Shop. From this modest beginning evolved the gigantic modern presses that form part of an airplane wing or the top of an automobile body with a single stroke.

Drawing operations are divided into two classes: "shallow" and "deep." The line of demarcation between the two is naturally fixed at the point where the depth of the draw is less than the diameter and where the depth may equal or exceed the diameter. The first is used mostly for such products as shallow tinware, shoe-polish and salve boxes, and parts of lamp sockets. These products can be made in a single-action press with an inverted compound die; the material is usually high brass or tin. A typical die for this class of work, in relatively small sizes, is shown in Fig. 267. Press tools of this design are sometimes called "combination blanking and drawing dies."

In large work, many difficult parts come under the classification "shallow." The entire turret top of an automobile is made at one blow. Fenders and radiator shells are similarly made. Probably one of the most difficult of these shapes is the front fender with its reverse bends. The difficulties in the way of such large work are identical with those in small deep-drawn work—wrinkles and fracture.

Drawing-die Principles.—The first steps in producing a drawn shell are illustrated in Fig. 268, at *A* and *B*. At *A*, the blank holder has descended ahead of the punch, and spring pressure *P* holds the blank taut, while the drawing punch continues to descend and "cups"

the blank into the die, as shown half finished at *B*. An air-vent hole through the punch is necessary to prevent vacuum resistance when stripping off the finished shell.

In a single-action press, blank-holder pressure *P* is produced by compression springs, by soft rubber, or hydraulically in some very large presses. With a hydraulic blank holder, blank-holding efficiency
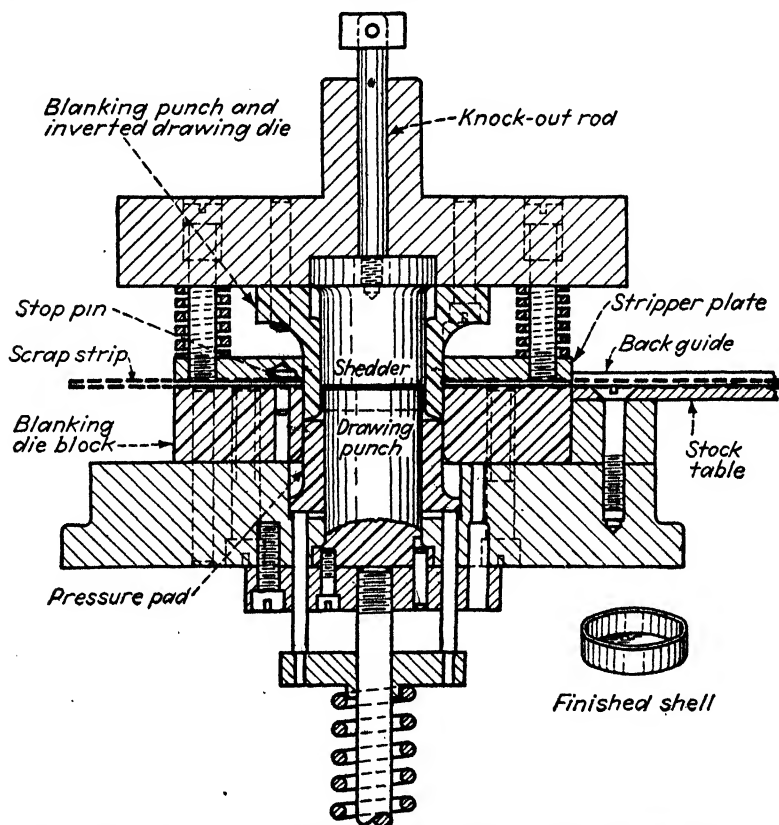
FIG. 267.—When drawing shallow box covers, lettering or trade-marks can be incorporated by placing stamps or characters in the punch face or shedder.

is greatly increased. Hydraulic pressures are constant throughout the operation, but compression springs increase and decrease in power relative to the position of the ram. A hydraulic blank holder permits deeper and better draws; they are also easier on the press.

In a double-action press, the blank holder is attached on the face of the outer ram. The outer ram descends first and holds the blank taut while the drawing punch descends through it and draws the blank into a shell within the die. The unilateral drawing clearance *D*

equals the material thickness; it is a uniform space extending all around between the punch and die. This space is sometimes made less than the material thickness for "ironing" the shell-wall thinner.

At *C* we have a well-known case in which the general rule—the depth of a single draw must not exceed the shell diameter—can be
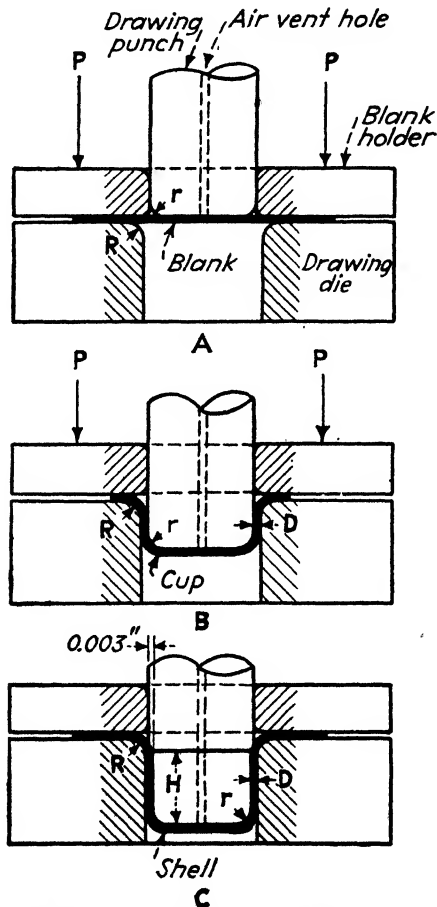
Fig. 268.—Illustrating several important principles involved when drawing shells from flat blanks.

easily evaded. A sharp shoulder 0.003 in. deep is provided around the drawing punch at height *H*, which is safely under the shell diameter and the prescribed rule. In this design the shoulder on the punch, in descent, will "bite" into the shell wall, thus relieving drawing tension on the end of the punch. This is a safe and sure method for drawing deep shells without fractured corners.

Computing Percentages for Shell Diameters.—If the diameter of a drawn shell is 9 in., and its blank diameter is 12 in., the shell diameter is a 25 per cent reduction, or 75 per cent of the blank diameter. Redrawing a shell from a 10- to a 6-in. diameter is a 40 per cent reduction, or 60 per cent of the original diameter. Most shops and designers use this computation method when considering redrawing of shells.

Sizes of Drawing Radii.—For sheet-steel thicknesses under No. 14 U.S. gage (0.078 in.), sizes of radii over the entering edge of the drawing die are very important. If these radii are too small, the work will rupture near the face edge of the punch or when entering over the die radius. Such ruptures are caused by the excessive friction generated by pulling the metal over an insufficient arc size. On the other hand, if these radii are excessively large, the material will wrinkle in passing over the arc entering the die. Obviously there is an ideal size of drawing radius that lies between these two extremes.

Although there is a fairly definite relationship between the stock thickness and drawing radius R, nevertheless the radius should be varied for large blanks and different tempers of metals. However, for ordinary work the following sizes for R have been found practical. For $\frac{1}{64}$-in. stock, use $\frac{1}{16}$ in. R. For $\frac{1}{32}$-in. stock, use $\frac{1}{8}$ in. R. For $\frac{3}{64}$-in. stock, use $\frac{3}{16}$ in. R. For $\frac{1}{16}$-in. stock, use $\frac{1}{4}$ in. R. For $\frac{5}{64}$ in. stock, use $\frac{3}{8}$ in. R. For $\frac{3}{32}$-in. stock, use $\frac{7}{16}$ in. R. For $\frac{1}{8}$-in. stock, use $\frac{9}{16}$ in. R.

The figures given refer to dimension R in Fig. 268. If R exceeds these figures excessively, the blank-holder tension cannot be adjusted to prevent wrinkles in the stock when it is drawn over the radius. Wrinkles once started cannot be removed; they will still show after several anneals and redraws. If radius r on the face edge of the drawing punch is equal to or greater than R, so much the better. Radius r should be as large as possible, especially in shells that are to be redrawn. Of course much of this depends on the kind of material being used and most of all on its deep-drawing qualities. Sheet-steel thicknesses above No. 14 U.S. gage (0.078 in.) can usually be drawn without wrinkling, even without a blank holder.

The usual specification for deep-drawing steel is S.A.E. 1010. The first 10 signifies an unalloyed carbon steel of high ductility, and the last 10 indicates a "10-point" carbon content. In the nonferrous metals, copper draws best; and in the brasses, admiralty metal and cartridge brass. Commercially pure aluminum (2S) is considered best for drawing, spinning, and forging. Using this metal in its annealed temper, drawn shells that require several successive operations can be made without the necessity of intermediate annealings.

Since alloyed aluminum is less ductile than the pure metal, it requires larger radii for bends and is used for less severe drawing than the pure metal.

Drawing Concave and Tapered Shells.—In certain shallow-drawing operations, where it becomes necessary to increase the tendency of the blank holder to stretch the metal more taut, bead A is provided around the die opening as seen in Fig. 269. This design is sometimes necessary when drawing certain shallow tapered shells. With no additional spring pressure at P, the holding and stretching power of the blank holder is thereby increased enormously. The tension power of the blank holder can be controlled by the shape, size, and depth of the bead. This design is usually not resorted to unless the material is
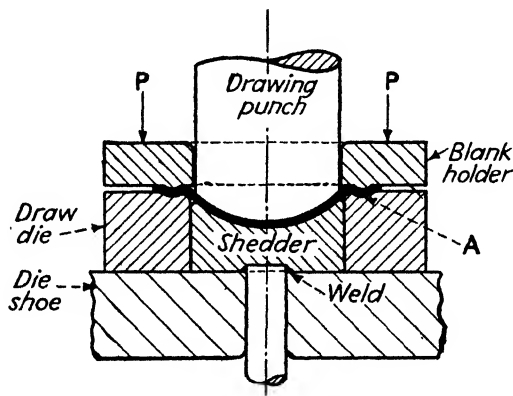
Fig. 269.—For shallow draws in steel, and sometimes for drawing tapered shells, bead A increases the stretching power of the blank holder without additional compression springs P.

steel. It will prevent wrinkles in steel that seldom occur when drawing the more ductile nonferrous metals.

Drawing without a Blank Holder.—Thick-gage metals can be successfully drawn through a die without the usual blank-holder pressure. Thin nonferrous metals are similarly drawn when the finished diameter is small relative to thickness. Figure 270 represents the usual design of the die. Radius R is made approximately five or six times the blank thickness to provide an easy draw into the die. Three or four equally spaced stripper slides, actuated by compression springs P, are forced to withdraw when the shell passes between them and close together after the shell passes; by this device the work is stripped from the punch in ascent.

The shell diameter should not exceed about twenty times the blank thickness; otherwise, wrinkles may appear in the drawn shell. This

principle is well known by manufacturers of cartridges and ammunition shells and for work in which the wall must be "ironed" thinner than the bottom in subsequent annealings and drawings.. The principle involved is that an extra-thick blank will be stiff enough to overcome
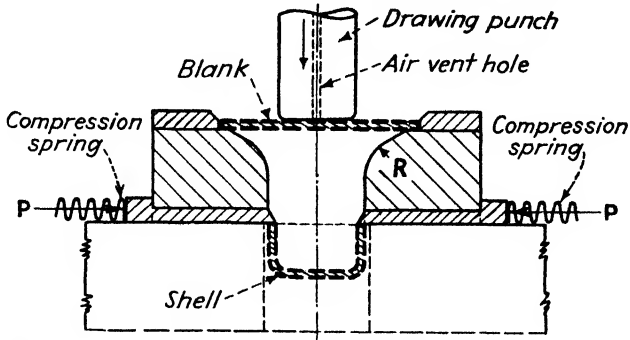
FIG. 270.—This die draws shells without a blank holder. Slides *P* automatically strip the shell from the punch when it ascends. The stripping device is optional.

wrinkling when the ram descends and forces the metal into plastic flow around the punch.

"Ironing" Shells to Reduce Wall Thickness.—Figure 271 shows the effect of redrawing an annealed shell when the drawing space between the punch and die is *less* than the original material thickness. The object is to produce a shell in which the bottom remains of original thickness but with side walls made thinner. This operation is frequently necessary in producing ammunition cartridges and shells. The working members of the die must be hard tempered, smoothly ground, and then highly polished in the same direction as the draw, similar to a burnishing die.

FIG. 271.—Redrawing an annealed shell and leaving a bottom of original thickness, but thinning the side wall by "ironing" the metal.

When drawing and ironing a shell, thinning of the wall obviously affects the computation of blank diameter. The mean height of the finished shell is approximately ht/T, in which h is the ironed height of the shell, t the ironed thickness, and T the original thickness of material. If a finished shell is 2 in. in diameter and 3.430 in. high and has an ironed wall 0.035 in. thick, and the original thickness of metal is 0.040 in., then by the foregoing formula

the mean height is

$$\frac{3.430 \times 0.035}{0.040} = 3 \text{ in.}$$

By consulting tables giving blank diameters of cylindrical shells, we find that a shell 2 in. in diameter by 3 in. high requires a blank of 5.29 in. diameter. This is a simple case where the wall has been reduced 12½ per cent. If the conditions are complicated by having a shell size not listed in the tables, then the blank diameter $D = \sqrt{d^2 + 4dh}$, and the mean height is used for h in this formula. Shell walls should not be reduced in ironing more than 10 to 12½ per cent for one draw, unless the material is very ductile.

Subdividing Operations.—The first law of good tool engineering is that subdivision of operations is a function of accuracy. The essence of this is that any function can be successfully performed in a sufficient number of operations. This law applies nowhere more truly than in the plastic working of metals. The trouble with the rule is that·it is in direct opposition to the principle of economic production, and we are allowed to follow it only when absolutely necessary. Presswork must be produced in as few operations as possible.

Plastic Flow in Drawing Metals.—To understand clearly how slip planes are caused inside the metal and just what occurs in plastic flow around the punch, when it forces the blank into a die in forming a shell, constitutes one of the basic principles of drawing dies.

A cup or tube of any length, a form of any shape, and a plastic metal of any description or thickness may be drawn if done in a sufficient number of operations, with properly annealed shells. It may be drawn thinner than the original metal, or it may be thickened up. For, after all, such operations are simply the application of bending, stretching, and upsetting operations which the blacksmith does every day. Heating the metal does not change the nature of plastic flow; it merely makes it easier.

In simple bending, the grain of the metal on the outside, or convex, surface is stretched beyond its elastic limit, and the crystals slide upon one another. In some metals the crystal structure is "short," or granular, and the crystals will not slide one upon the other sufficiently to allow bending on a short radius. So the metal fractures. Cast iron is a good example of this; antimony is another.

Crystallization of some other metals is "stringy," and the flow planes are quite long and definitely perceptible under the microscope. Copper and particularly lead are good examples of this. Such metals will flow easily in any direction. Some metals, such as high brass

and Bessemer steel, have short flow lines but may be made more plastic by rolling into sheets.

Low brass and open-hearth steels, on the contrary, have practically no grain and will flow under pressure in any direction. In a sufficient number of operations, low brass and open-hearth steel can be worked more economically; therefore, they are preferable for certain operations.

It is not impossible to draw a wash basin from a cast-iron blank, given time and enough operations. Knots have been tied in piston rings, and cast-iron automobile valves have been cold forged on a production basis. All this may not have connection with presswork, but it demonstrates that all metals are subject to plastic flow if given time and if properly normalized between operations.

In drawing operations the forces are largely compressive. There is extensive plastic flow and a violent rearrangement of the crystals in the metal. To illustrate, take a blank $4\frac{1}{2}$ in. in diameter, and from it draw a 2-in.-diameter cup. First, scribe two parallel lines across the face of the blank, one on each side of the center line and $\frac{1}{2}$ in. apart (Fig. 272). With the blank held tight enough to prevent wrinkling, lower the press ram so that the punch descends 1 in. below the top of the drawing die, and the shell is drawn 1 in. deep. Upon removal of the shell, the lines will be found still parallel and $\frac{1}{2}$ in. apart across the bottom of the part. Thus, no disturbance has occurred in that area. On the vertical walls, the lines converge toward each other

Fig. 272.—Parallel scribed lines in the blank will be found to converge from the periphery to the drawing edge, showing that considerable plastic flow must occur if metal is to be made to pass through a constricted space to become a shell.

and at the top are about $\frac{3}{8}$ in. apart. On the flange, the lines diverge in opposite directions; they are $\frac{3}{8}$ in. apart at the shell walls and $\frac{7}{16}$ in. apart at the outer edge of the flange.

During the drawing operation, stresses are set up in two directions. Those in the vertical walls are tension stresses, caused by the punch drawing the metal over the edge of the die at nearly right angles against

the resistance of the flange to flow.   The stresses in the flange, under the blank-holder pad, are necessarily compressive, caused by the violent effort of a larger area of metal to crowd itself into a smaller area without increasing in thickness or wrinkling.   Like a large flock of sheep passing by twos and threes through a narrow opening, there is no trouble in either case unless the operation is hurried. This suggests that drawing-punch speeds must be reasonable; the appearance of the first drawn shells usually indicates that a slower punch speed is necessary.

When the shell has been completely drawn, the positions of the lines will be like those in the lower view of Fig. 272.   The distance
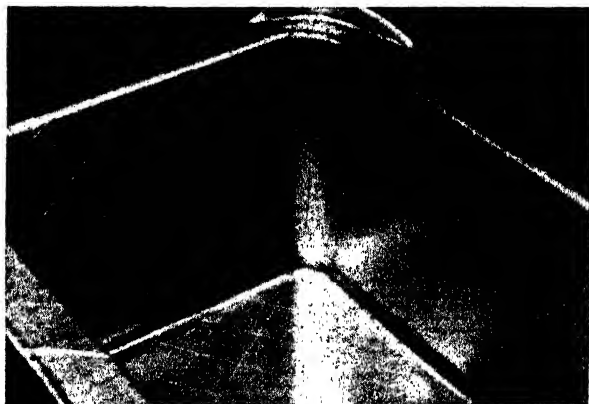
Fig. 273.—Equal squares scribed on a blank before drawing show the flow lines of metal when drawing a rectangular shell.   The convergence of lines in the corner is especially noticeable.   (*Courtesy of Aluminum Company of America.*)

between the lines at the top of the shell is now less than $\frac{1}{4}$ in., or one-half the original distance.   Apparently there should be the same amount of material around the top of the shell as in the periphery of the blank.   But is there?   No, because a blank circumference of $14\frac{1}{8}$ in. has been crowded into one of only $6\frac{9}{32}$ in. around the top of the shell.   Where has the extra metal gone?   Part of it has been used to build the walls of the shell higher.   It will be found by measurement that the area of a blank $4\frac{1}{2}$ in. in diameter is the same as the area of a cup 2 in. in diameter by 2 in. deep.   This presupposes that the metal has been ironed out to its original thickness.   This, in turn, depends upon the physical properties of the metal to withstand the necessary stresses without wrinkling or tearing.   It should be remembered that a metal should never be drawn beyond its elastic limit.

If the 2- by 2-in. shell is of good plastic material, it may be annealed and redrawn to another shell, $1\frac{1}{2}$ by 3 in., and next into a 1- by 5-in. shell, and finally to a $\frac{1}{2}$- by 7-in. shell. Shells of these dimensions are made in large quantities for subsequent expanding operations in hydraulic or, more properly, hydrostatic die work.

Figure 273 represents an actual photograph of a drawn shell, or rectangular pan, shown before trimming, curling, and wiring the top. The flow lines of the metal are seen to converge toward the top, and especially at the round corner where the drawing conditions are similar to the cylindrical shell, scribed with parallel lines as described just previously.

Designing a Drawing Die.—In designing or making a drawing die, the first thing to remember is that the shell hugs the punch and that the size of the punch governs the inside dimensions of the shell. As the punch descends and the diameter of the flange held by the blank-holder pad decreases, the shell will hug the punch less tightly at the end of the draw. Where the metal flows over the radius at the top of the die, it is not held at all. Depending upon several factors, this metal may remain smooth, but a microscopic examination of most shells will show short wrinkles that have been ironed out under the pressure pad. Being under no drawing tension, this part does not hug the punch so closely. Furthermore, the top is usually thicker than the rest of the shell, because it has not been under drawing tension.

This characteristic of the shell to hug the punch causes trouble in stripping and is the secondary cause of many accidents. The operator may be running a double-action press continuously, and the finished shells will drop through the press regularly. But a shell may fail to strip, and at the next stroke the press tries to draw two shells at the same time in the same die.

This trouble has led to the design of many types of strippers: Some of them are freakish; some are good. Ordinarily it is not necessary to use a special stripper on metal $\frac{1}{8}$ in. or less in thickness. On heavier metal a special stripper is required because the force necessary to strip the shell is greater than the resistance of the top of the shell to shear off against the stripping edge on the die. The need of a stripper is evident here because every shell will come up.

For thin shells, the easiest way to strip the punch is to cut a stripping edge below the drawing edge of the die. This edge should be undercut, and the top of it should be less than 90 deg. with the inner surface of the drawing die, as shown in Fig. 274. The inner surface

of the die should be perfectly straight, or even taper inward a trifle, as it approaches the bottom. The metal springs away from the punch slightly at the top of the shell, because it is not under the tension of the blank-holder pad. After the finished shell is pushed through the die, it cannot go back through the same hole when the punch ascends, if there is something to catch against the upper edge of the shell. A stripping edge (Fig. 274) performs the function. A stripping device for heavy shells is shown in Fig. 270.

Small shells are sometimes stripped by a floating split ring which is substituted in place of the stripping edge. The ring is of tempered
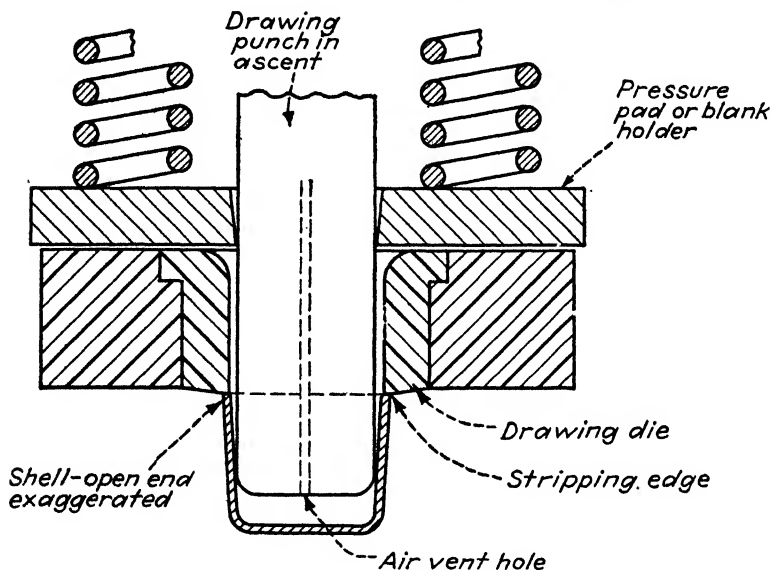
Fig. 274.—Since a drawn shell cannot follow up with the punch and through the drawing die from which it came, it is possible to strip off the piece by an undercut edge shown around the bottom of the drawing ring.

spring steel, and the closed diameter of its hole is about 0.005 in. smaller than the outside diameter of the shell. The drawing punch, in descent, forces the finished shell through the ring, and the ring closes above the shell. When the punch ascends, the shell is stripped off by the ring. An air-vent hole should be provided through the punch in all cases. This prevents vacuum resistance when stripping off the shell.

The first precaution to observe in any drawing die, regardless of the type of stripper, is to provide a safety link above the punch or a key through it, that will break or shear off when two shells accidentally

get in the die. The next thing is to note whether the shell came up through the die intact or with the upper edge of the shell nicked. If the former, the die is set eccentric, the highest part of the shell happened to be at the point of maximum clearance and came up through the opening thus left, and the rest of the shell followed as a matter of course. If the edge of the shell is nicked, the punch needs polishing. The nick indicates that the shell adheres too tightly on the punch. Polishing should always be done lengthwise of the punch. For thin copper shells, crocus cloth should be used in the same manner; a microscope will reveal the reason. The copper, in hugging the punch, is soft enough and hugs hard enough to enter every tiny cross scratch.

Other devices for stripping the punch of drawn shells, in addition to those already described, are probably not necessary. An extra stripping device will most often entail unnecessary cost. In too many cases, strippers are added to cure a trouble instead of rectifying the cause. However, for tools made on contract or placed in production under an inefficient foreman or die setter, an extra stripper is an added precaution. It may prevent damage to the dies and eliminate the usual complaint that "the dies were not made right." On shells of thick material they are a necessity because the shell does not flare enough, at the top and around the punch, to resist shear when stripping under the die.

Another thing to bear in mind is that the angle of the flat surface of the die under the blank holder (Fig. 276) and the size of the radius leading into the die control the drawing of the shell. When the angle is too obtuse or the radius is too large, the shell will wrinkle. When the angle is too acute or the drawing radius is too small, the shell will rupture. A single-operation shell may be "ironed out" more easily by the angle of the flat than by making a tight fit for the material between the punch and die. The pressure exerted by the blank holder, or pressure plate, is not positive and cannot be controlled accurately; therefore, it is best to vary the angle.

For any shell that is to be redrawn, the first drawing operation should not be ironed out. The proper way is to draw the shell without wrinkles and to leave the ironing until the last operation. By this procedure, the dies will last longer and require less polishing, and there will be fewer stoppages for digging out fractured shells.

Some Defects Are Impossible to Correct.—The next thing to remember is that a crack, wrinkle, or thin place in the wall of the shell

can never be ironed out. The first two may possibly be glossed or burnished over, but they are likely to show again at any time. The radius on the face end of the drawing punch should always be as large as possible to avoid trouble, especially in redrawing shells. A desirable condition is to make the flat bottom of the punch the same diameter as the final drawing operation, even though only the flat can be that diameter. Otherwise, corner ridges will appear on the sides of the shell, and much time and expense may be spent in trying to smooth out these marks. The best way is to keep such defects out in the first place or at least keep them where they belong.

That part of the blank between the outside diameter of the punch and the top of the die radius is not confined in any way. When the punch contacts the blank and starts down, this unsupported area is in tension. Instead of wrinkling like the rest of the blank, it has a tendency to stretch. The degree of stretching depends largely upon the tension on the rest of the blank, which in turn depends upon the compressive power of the blank holder. Whether this stretch takes place uniformly over the exposed surface or at one point depends upon the size of the radius around the lower end of the punch. A sharp-cornered drawing punch will act as a blanking punch and cut through the blank in spite of the die radius. A small radius will cause most of the thinning to be done just above the radius on the punch. Just how far the thinning at this point will go depends upon the resistance of the remainder of the blank to plastic flow. The resistance may be so great that the bottom of the shell will be punched out.

Analyzing Redrawing Operations.—When a shell is redrawn, the following conditions are present: The bottom is of original material thickness, but a part of it will be drawn up on the vertical sides of the shell. Immediately above it is a thinned ring of metal which will hug the redrawing punch and tend to accentuate the ridge caused by the thick metal of the bottom. If another redrawing operation is necessary, the ridge will obviously move up on the side wall, and another ridge, not so prominent perhaps, will show below it where the next corner turned. These ridges cannot be entirely removed. In any ironing operation that involves stretching, the thin part will stretch uniformly with the thick part. Even though it may be fairly invisible, the weakness still remains. On the other hand, the radius on the bottom of the punch must not be made too large, because the unconfined metal along the radius may wrinkle. The hardest shell to draw is a semisphere, or one with considerable taper (see Fig. 269).

How to "Read a Shell."—If the bottom punches out at the beginning of the draw, the pressure pad should be released slightly. If it occurs halfway down, the angle on the die under the blank holder is too acute. If lower down, the reduction is too great for the grade of metal used, either because of "short" grain, not sufficiently annealed, or because the punch and die are too small in proportion to the size of the blank—in other words, too much of a reduction. If the cups fracture on one side, reset the die concentrically. If the side of the shell is burnished all the way down and the bottom punches out, there is not sufficient clearance between the punch and die. If only the upper half of the shell is burnished, the clearance between the punch and die is about equal to the thickness of the original material.

If the outer surface of the shell has vertical scratches, the lip of the die, just below the radius, is becoming "loaded." The trouble is more than likely caused by too great a drawing speed. The cure may be more or better lubricant, a harder temper in the drawing ring, or finally slowing down the speed of the press ram. The first thing to do is to polish the radius inside the drawing ring. The same rule obtains here as with the punch; the polishing should be vertical and in the direction of the draw. Scale on annealed work will sometimes scrape off on the radius and wedge between the cup and the die, thus causing scratches.

Sometimes the metal used for drawing has such a high tensile or breaking strength that it can be overworked without rupturing. In such cases the shell may show a network of small cracks, which may break afterward. We might then lay it to aging cracks. The only remedy is to add a sizing operation.

If the shell comes out of the die with one side much higher than the other, the die may be pinching on one side, the stock may be thicker on one edge, or the blank holder may be pinching at one place. First turn the material over and see if the high place comes on the opposite side of the shell. If it does, the stock is at fault. If not, measure the walls and ascertain if one is thinner. If so, move the die in relation to the punch. Even then it may be the blank holder. So before shifting the die, it is better to test the tension between the die and the pressure plate with tissue paper. This test quickly determines whether the horizontal pressure is even all around the die or, if uneven, where and how much.

Drawing, Redrawing, Trimming, Piercing, and Curling.—Figures 275 to 281, inclusive, show six consecutive drawing operations for

producing the "curled-in" shell sketched in Fig. 275. This shell involves drawing, redrawing, trimming, piercing, and curling.

The first operation (Fig. 276) shows the angle on the die surface under the blank holder, the die-drawing radius, and the open space
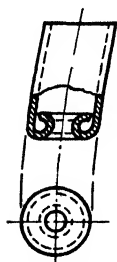
FIG. 275.
The work, an open-end drawn shell with a curled-in bottom.
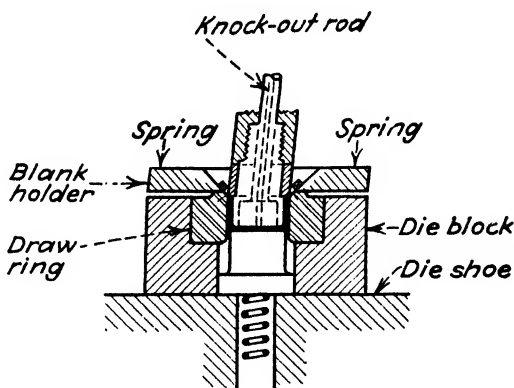
FIG. 276.—First operation, draw and pinch trim.

between the punch side and the top of the die radius. In the second operation, the shell is drawn *up* into a die over the punch (Fig. 277).
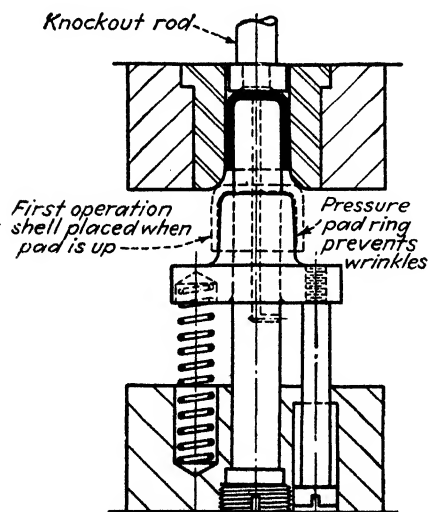
FIG. 277.—Second operation, redraw.
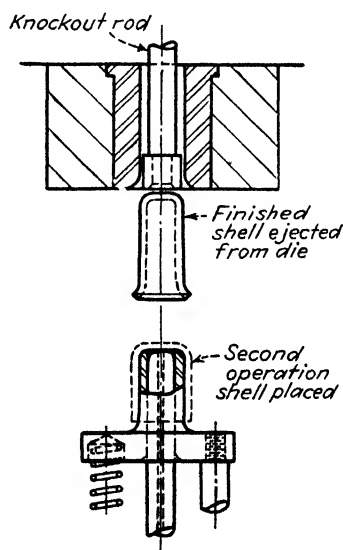
FIG. 278.—Third operation, redraw.

The third draw is similar to the second (Fig. 278), but leaves the shell mouth flared for an even trim in the next operation. When the ram

ascends, the finished shells are ejected from the die by the operation of knockout rods.

A pinch-off trimming operation is next required (Fig. 279). The shell is ejected from the die by a shedder and from the punch with a knockout rod. Piercing a round hole in the bottom of the shell is done in Fig. 280. The shell is carried up with the punch ascent and is stripped off against a positive plate, or hooks can be used. The final operation is reverse drawing and curling. This operation is finished and spanked to size at the maximum downstroke of the punch (Fig. 281).

In computing cylindrical shell blanks, the diameter used for the finished shell is the inside diameter plus the material thickness. In the foregoing cases the trimmed

FIG. 279.—Fourth operation, pinch trim.

height of the finished shell must be increased to include two trimming operations and the blank diameter must include these. Then the
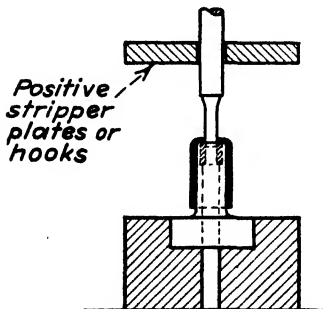
FIG. 280.—Fifth operation, pierce bottom.
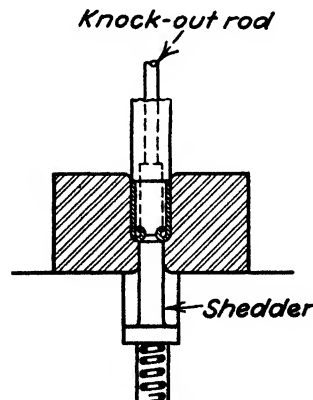
FIG. 281.—Sixth operation, reverse draw and curl.

blank diameter, or D, $= \sqrt{d^2 + 4dh}$, in which d is the shell diameter, and h its height. This computation is sufficiently accurate in cases where the shell-corner radius is very small. The

blank diameters for shells with large corner radii are determined in Chap. XXIII.

CHECKING DRAWING DIES FOR BREAKS IN SHELLS

In drawing first-operation shells, if breaks occur, these usually appear in torn openings around the sides of the shell, in a horizontal plane near the bottom of the cup. Such splits are more apt to appear when drawing light-gage stock, less than $\frac{5}{64}$ in. thick, or when using the less ductile metals.

Checking the Tool for Shell Breaks.—When this trouble arises, a systematic checking of the stock and the tools should be made. First, after ductility, should be considered the depth of the draw. The depth should not exceed the diameter of the shell, if other drawing operations are to follow. This precaution prevents weakening the bottom radius in the shell, which usually results in breaks in second or third drawing operations, if not in the first. If the piece requires only the first draw, the depth can often exceed the diameter considerably, depending on the thickness and ductility of the stock.

Sizes of the Drawing Radii.—The next items to be checked are the sizes of the drawing radii on the end of the punch and especially over the entering edge of the drawing die. If these radii are too small, the work will tear near the face of the punch or when entering over the die radius. This tearing is caused by the excessive friction in pulling the metal over an insufficient arc size. On the other hand, if these radii are excessively large, wrinkles will appear. The practical sizes for drawing radii have been previously determined in' this chapter under *Sizes of Drawing Radii* (page 303).

Other Causes for Broken Shells.—If shells continue to tear at the same place, there are two causes for this fault. Either the punch does not operate concentric with the die opening, or there are uneven high spots on either the punch or the die or both.

Other causes for shell breaks are too much blank-holder pressure, improper lubrication, and the use of oversize stock. The latter requires very accurate checking.

An occasional break may be caused by hard spots, grain growth, or rolled seams in the sheet. These faults can usually be ignored, unless the ruptures occur too frequently, in which case more rigid specifications should be made for purchasing future material.

Breaks are sometimes caused by an attempt to "iron" the metal between the punch and die, by reducing its thickness too much in a single draw. No more than 0.003- to 0.004-in. reduction for a single operation should be allowed for sheet metals between $\frac{1}{32}$ and $\frac{1}{16}$ in.

thick. A safe rule is 10 per cent of the material thickness, if the stock is very ductile.

Time for Metal Flow 'Is Important.—Drawing operations must include sufficient time to allow the metal to flow from its previous form into the new   The drawing of metals produces a violent disturbance of the molecules; and unless sufficient time is allowed for the necessary rearrangement of the molecules, their adhesion is destroyed, and the metal tears. The remedy for this is to decrease the traveling speed of the drawing punch. For drawing light stock, under $\frac{1}{16}$ in. thick, the speed of the punch can be moderately fast; but as the thickness of the stock increases, the speed of the punch must be proportionally slowed down.

Providing Vent Holes in the Punch.—The lack of an air-vent hole through the punch adds to the difficulty of stripping the work from the drawing punch; and if the metal is very thin, this oversight may cause a distortion or sometimes a rupture in the finished shell. Tapering the punch slightly helps to "strip" off the shell.

Annular grinding lines around the punch or die prevent easy stripping. These lines should have been polished out, in a lengthwise direction, parallel with drawing.

Breaks That Occur When Redrawing.—Breaks in shells often show up in second or third redrawing operations, because the bottom of the cup, in cross section, was not drawn to the proper shape in the previous operations, suitable for subsequent draws. The flat bottom of the cup diameter should not exceed the size of the redrawing die diameter; if it does, breaks are likely to occur when the corner radius on a greater diameter is redrawn to a smaller diameter. The corner radius in the bottom of a previously drawn shell is the weak point in the work; redrawing to a smaller diameter often results in ruptures at this point, if the stock is less than $\frac{1}{16}$ in. and even though annealed before redrawing. Metals of greater thicknesses may not tear from this cause, but it is safe to avoid this chance when redrawing any thickness.

Avoiding Breaks in Successive Draws.—If it is necessary that the flat-bottom diameter of a previous draw must exceed the diameter of the next redrawing die, the chances for breaks are greatly reduced in subsequent draws if the corner radius at the bottom of the shell is omitted and the bottom is drawn semispherical instead. This design avoids the redrawing of a small radius (already crystallized), a common cause for torn shells.

Turning Shells Inside Out.—This operation is resorted to for obtaining a finished tapered shell; it also avoids extra operations.

The metal should be of light gage and the highest quality of deep-drawing stock. The first operation should have a shell bottom of large radial corners; this shape is the ideal condition for turning shells inside out (Fig. 283). Annealing after the first operation is usually necessary. Annealing and lubricating of ferrous and nonferrous metals is treated at length under Chaps. IV and V.

The Cause and Cure of Wrinkles.—Probably the greatest difficulty in drawing sheet metals is the tendency of the blank to wrinkle. Wrinkles may worry the die engineer and the toolroom and pressroom foremen considerably if they have no remedy at hand. The cause and cure of wrinkles is a long story. The only cheerful part of it is that they occur only when metal is under compressive strains, never under tension. Of course this fact is self-evident, but the obvious thing is too often overlooked in many engineering designs. By remembering that fact and the maxim "when mechanical laws oppose, reverse your practice, and make the opposition help," we may be able, at times, to reverse our method and substitute tension. Turning a shell inside out is a good example of this.

Before attempting to describe the cure for wrinkles, it is best to review what we think we know about the nature of wrinkles in their practical relation to presswork. Wrinkles arise from three causes: resistance to plastic flow, unconfined metal, and drawing at too rapid a rate. Taking them in their order, plastic flow is a condition that allows molecular movements within the metal; it results in a rearrangement of the grain structure without decreasing the strength of the piece.

Elsewhere in this chapter it was said that plastic flow, or, as a mechanic would call it, "upsetting," in presswork did not differ from the same operation done by a blacksmith. It was also said that heating the metal in a forge did not change the nature of the operation but only made the metal flow more easily. The same condition is true of wrinkling. It occurs just as readily in boiler plate as in thin steel and also in bar and flat stock, if the piece under compression is unsupported for several times its diameter or thickness.

From the largest bolt header down to the smallest rivet-forming machine, the unsupported length of metal that can be successfully upset or headed, under compression, is about $1\frac{1}{2}$ times its body diameter. If the wire or rod is unsupported beyond that length, it will bend, buckle, or wrinkle. Heavy sheet-metal structures must be braced and stayed to prevent bulging or buckling under their own weight. Every bulge or buckle is the beginning of a wrinkle.

Controlled wrinkles are one of the most useful expedients in press-working of metals and nonmetallic materials. Curling, wiring, and stamping are examples of controlled wrinkles. In fact, we might call any bending, shaping, or bulging operation a controlled wrinkle partially completed. The "Lily" paper drinking cups that we so often see are simply a round disk of paper artistically wrinkled up the sides and curled at the top. These and hundreds of other examples demonstrate that wrinkles are both useful and ornamental as well as an unwanted condition in press drawing of shells.

Looked at in that light, the solution of our problem is reduced to simply controlling the wrinkles and causing them to occur only when and where we want them. More easily said than done, perhaps, but more easily done if we understand what causes wrinkles and how they start. As already stated: theoretically they are caused by the inability of unconfined metal to withstand the force necessary to cause plastic flow.

Let us illustrate this by examples of uncontrolled wrinkles and then show how, with proper support, they could have been controlled. We shall take a blank 6 in. in diameter and $\frac{1}{16}$ in. thick and center it over a 2-in. cylindrical drawing-die opening. We are not interested in the form that the wrinkles will take if the blank is wholly unconfined, but we do want to know what happens when the blank holder or pressure plate is too loose. We shall therefore conduct the demonstration by adjusting the blank-holder pressure plate $\frac{1}{2}$ in. above the die. We already know that plastic flow cannot take place if the blank is pinched too tight between the blank holder and the die face. We have punched the bottom out of enough shells to learn that.

With the punch down against the blank, we lower the press ram by hand about $\frac{1}{4}$ in. We can hear the edges of the blank slap against the blank holder, as the blank perimeter tries to fly up tangent to the radius around the top of the die. We lower the ram another $\frac{1}{4}$ in. and observe that there has been absolutely no plastic flow in the material. The diameter of the blank has decreased an inch or more, and we notice that five large folds, or wrinkles, have started. One wrinkle is quite wide; three, smaller but fairly uniform in size; and one, considerably smaller. The places where the folds occur do not seem to bear any relation to the grain of the metal. If they had any such relation, there would have been an equal number of folds. As it is, they represent the five weakest places in the blank, due to either grain or defective crystalline structure in the metal or both. Possibly their positions are caused by uneven annealing. Anyway, they are

the five places where the metal failed first.   The smaller fold appears to be surplus metal left over after the other wrinkles were formed.   In its present condition the work is a nice ash receiver or card tray, indicating how some of those articles are made.

Watching the blank where it bends over the radial entrance to the die to detect indications of fracture, let us bring the ram down another $\frac{1}{4}$ in. and thus reduce the blank diameter still more.   The sides of the folds have now assumed a vertical position.   There is no change in the number of wrinkles or in the width of the flat at their tops.   This shows that the movement caused by lowering the press ram is bending the metal at the places where it joins the upper and lower flats of the folds, in other words, the metal that is not horizontal.   The lower parts of the folds are pressed hard against the face of the die, and the upper parts are pressed hard against the under surface of the blank holder.

The direction of force caused by the attempt of the blank to become smaller in diameter is wholly compressive and therefore horizontal. No more folds will appear until the strength of the horizontal portion is less than the resistance of the nonhorizontal parts to further move-ment.   We lower the ram another $\frac{1}{4}$ in. and notice a decided decrease in the power necessary to do so.   This is a warning that something has happened or is about to happen.   We raise the punch and blank holder and examine the cup before removing it.   We find that the inner points of the folds have crowded into the radius around the top of the die, and, there being no more space between the punch and die for more than one thickness of material, the folds cannot enter.   The result is that the last lowering of the ram stretched the metal in the vertical part of the shell beyond its elastic limit, and there is probably a fracture at some point around the cup.   We observe further that the vertical sides of the five folds have folded under and that we now have five true wrinkles.

Even were it possible, it would serve no useful purpose to carry the demonstration further.   We have witnessed the complete cycle of producing wrinkles.   What has occurred in this case is exactly what takes place every other time where wrinkles occur, except that under *some* blank-holder pressure, they have a narrower space to form in and are therefore much smaller and more numerous.

If we had been able to carry the experiment further, we should have seen the edges of the large wrinkles come together and other folds and wrinkles occur at the weakest spots on the flat surfaces of the large wrinkles.   These would keep on multiplying until the diam-eter of the flange was reduced to the die diameter.   These wrinkles could not happen if the face of the blank holder were brought down

on the material parallel with the flat surface of the die and so held to prevent the metal from raising and folding. The obvious solution for all wrinkle troubles would be to confine the material, in some cases with the blank holder, in others by the clearance allowed between the punch and die, and lastly by using tension or stretching methods instead of compressive.

Metals of any thickness can be drawn into annular or shell forms without using a blank holder or pressure pad, if the diameter of the blank is small enough in relation to the thickness of metal. In very thin metals this proportion is a blank about $1\frac{1}{2}$ times the diameter of the die opening. This proportion of blank diameter to the die opening increases gradually as the metal thickens. Tables should be compiled covering this subject; the author knows of none at present. But he does know that when $\frac{1}{8}$-in. material is used, we can draw a cup of any reasonable size without wrinkles or using a blank holder. This is because the resistance to buckling is greater than the resistance to plastic flow. In other words, the blank is too stiff to fold into wrinkles. A die for this purpose is shown in Fig. 270. In some cases, notably in the case of drawing tapered shells, the flange may be confined so that no wrinkling occurs, but the cup wrinkles badly in the die. The cause is the same—unconfined metal. The principle involved in drawing tapered shells is a preliminary undersize reduction and then stretching the shell to size in two or more operations.

Drawing Tapered Shells by Stretching.—Figure 282 shows a tapered shell A, as produced in one "draw-taper" operation from shell B which was previously prepared in two ordinary drawing dies. This principle is used for converting a previously drawn shell, having one or more reductions or steps, as shown at x and y, into a smoothly drawn tapered shell by stretching it out to size. The number of steps required, as x and y, depend upon the depth of the finished tapered shell. Sometimes as many as five steps are required. Metal

Fig. 282.—Expanding a previously prepared shell into a tapered shell.

ductility also enters the picture in producing tapered shells by this method.

Reverse Drawing Straight Shells and Tapering.—In Fig. 283 shell A has been previously prepared and trimmed in an ordinary drawing and "pinch-trimming" die. The shell is placed mouth down over the redrawing ring B. Tapered punch C then descends and redraws the shell through the ring and over the generous size of radius R, as

shown in the lower sketch, where the work is about one-third com-
pleted. This operation is sometimes called an "inside-out job"
and is a principle often resorted to for producing tapered shells. There
are no chances for wrinkles to occur in this operation, because we have
changed the forces of compression, which causes wrinkles, to those of
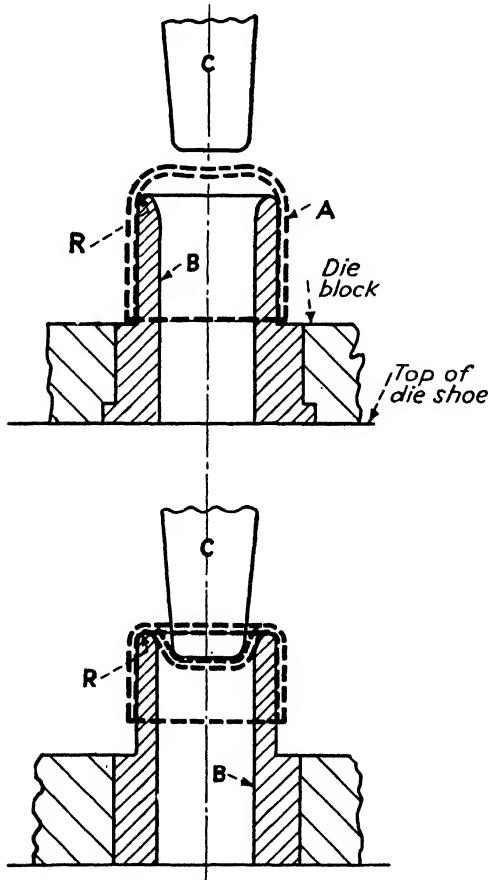
Fig. 283.—Reverse drawing, or turning a shell inside out.

tension, which prevents wrinkles. Sheet metals up to about $\frac{5}{64}$ in.
thickness, if very ductile, are used for reverse drawings. The temper
of the shells is usually normalized by heat-treating them before
redrawing; this may prevent tears or checks in finished parts.

In reverse drawing operations, the depth of the finished shell
should not exceed $1\frac{1}{2}$ times its diameter. If the drawing depth is
too great, the bottom of the shell will rupture before all of the metal

has been pulled into the die. Drawing radius R should not be less than $3\frac{1}{2}$ to 4 times the thickness of the material being drawn. Remember that in all drawing operations, light gages of stock are more likely to wrinkle than the heavier gages.

Copper and brass can be reverse drawn to lesser diameters than steel, compared with using the same gage sizes of steel, or even when using gage sizes heavier than steel.

Other Methods for Tapering Shells.—A tapered punch and die that will draw the material between them cannot be made, so we use a tapered punch and a straight die. The tendency of the metal being to "follow" the punch, we can with some diameters, materials, and thicknesses draw a tapered or semispherical shell without wrinkles. But in order to do so it is necessary to use material heavy enough to permit the flange to remain practically stationary while stretching the cup from the blank, thus reducing its original thickness. In other words, we must stretch the drawn part beyond its elastic limit to produce this kind of tapered shell. What we call a "flat" concave or convex shallow cover used on cooking utensils is produced in this way. The more shallow a cover is the more difficult it is to draw. Figure 269 gives an example of a die for drawing shallow covers.

In the case of the tapered cup we have several alternatives in removing wrinkles, depending, of course, upon the thickness and strength of the material used. In some cases, such as cooking or kitchen utensils of either stainless steel or other steel that is to be enameled, the wrinkles can be spun or burnished out. Two "nested" utensils can be spun or rolled at the same time. At first it seems impossible that the inner utensil would receive any benefit from what is being done on the outer one. When we consider that the burnishing roller makes contact at only one point and that the two utensils are really eccentric to one another by reason of this one-point contact, it is not so remarkable. With thin-gage tinware it is possible to burnish several at once, but the usual practice is two.

Burnishing out wrinkles is an expedient not recommended for more important work where strength or finish counts. The remedy in these cases is either to make the article step by step with a final operation that stretches the metal or, in other cases, "inside-out drawing."

Punch Speeds for Drawing.—In all drawing operations it should be kept in mind that the rate, or speed, of drawing is an important factor. Plastic flow is not a rapid operation in any metal. If the punch speed is too great, the tendency to wrinkle is considerably increased. Proof of this fact is that we can often draw a perfect shell

where we work the ram by hand but that when we use power, the shells wrinkle. The resistance to plastic flow increases as the diameter of the blank is reduced. This is because of "work hardening." The resistance finally increases to such an extent that annealing the shells becomes necessary.

The same rules that apply to wrinkling in a flat blank apply also to redrawing shells. The same tendency of the flat bottom to wrinkle is present, if too much of it is unsupported, in other words, if too much of a reduction is attempted. With thin shells, this tendency to wrinkle is so great that at times it becomes necessary to redraw in a double-action press with the outer, or blank-holder, punch holding the cup in shape, as the pressure pad does on a flat blank. In thicker material the resistance to wrinkling is increased by the vertical walls of the shell in the same way that thick metal blanks resist wrinkling.

After a shell has been drawn, there are times when we wish to reduce the diameter at the top—to "neck it in" as the expression is. We find the same inclination to wrinkle where the compressive force is applied faster than the metal can flow. As in the case of the flat blank, the resistance to flow is caused by work hardening of the metal. Also like the flat blank, a controlled wrinkle around an annular shell or tube has certain commercial uses.

There is this difference, however: Whereas the wrinkles in the flat blank fold over and reduce the diameter until it finally becomes the same diameter as the cup being drawn, the wrinkle in an unsupported tube bulges and makes a larger diameter.

The first tendency of a tube under vertical stress is to slightly reduce its diameter, but the force necessary to thicken the tube by causing a flow of metal is greater than the force necessary to expand it. Therefore the compressive strains are translated partly into expansion strains, and the tube expands horizontally and collapses vertically. If the downward movement is continued, another wrinkle or bulge appears, somewhat smaller than the first, because the metal adjacent to the first wrinkle has become work hardened. This inclination of the tube to flow inward and expand outward makes it possible to locate the position of a controlled wrinkle by supporting the tube either inside or outside.

Increasing the Thickness of Shell Walls.—The usual process of drawing a shell produces a wall of fairly uniform thickness. There are times, however, when we require one part of the shell wall to be much thicker than the original material. This may be accomplished in several ways. The heavy and light part may be brazed together or, if of steel, may be copper brazed in a hydrogen furnace. This latter

is done on certain parts of an electric refrigerator. Another way is employed in the manufacture of 3-in. (75-mm.) cartridge shells. The original material is a very heavy blank, slightly thicker and larger in diameter than the head of the cartridge. The surplus metal in the diameter is gradually ironed out to form the body of the shell. Still another way is to use a blank of the thickness desired for the body wall and then increase the thickness at the desired place. This is the method with which we are concerned at present.
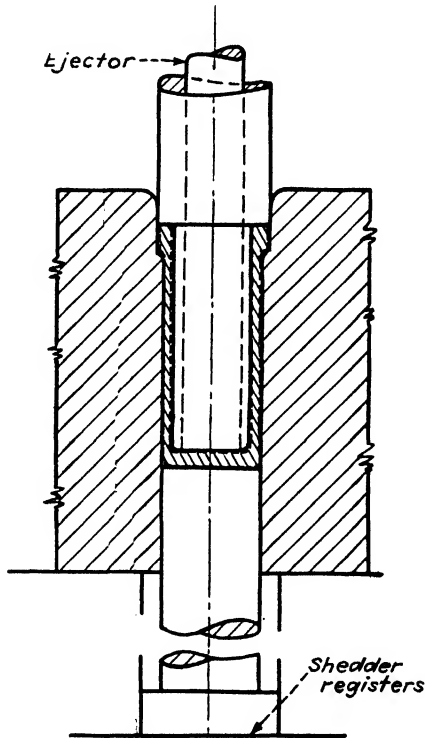
FIG. 284.—Thickening the mouth of a shell by forced plastic flow to provide metal for threading.

At the beginning of the first World War the body of the French type of fuse shell was turned from the solid bar. It was a difficult job because of the taper inside and out. Manufacturers had not yet begun to use a forged blank for turning shells. They could not be drawn because the rim at the top had to be threaded. Eventually someone discovered that the shell could be drawn and that its rim could be thickened up. This was obvious, of course, if there is any such thing as plastic flow in metals. The same principle applied here

as was described in upsetting bolts and similar parts. Upsetting
the end of the fuse body was merely a question of supporting it so
that it would flow and thicken at the end, instead of collapsing. The
same rule of 1½ times the diameter or thickness held good in both
cases. Figure 284 shows the principle.

When we say that a bolt length of 1½ times its diameter may be
upset without collapsing, it does not mean that only that length of
bar can be upset. A bar 1 in. in diameter may be upset in increment
of 1½ in., if the rest of the bar is supported while one part is being
upset. The same thing is true in a shell. Thickness may be added
at any part of the shell and to any practical thickness, if the rest is
confined to support the part being upset.
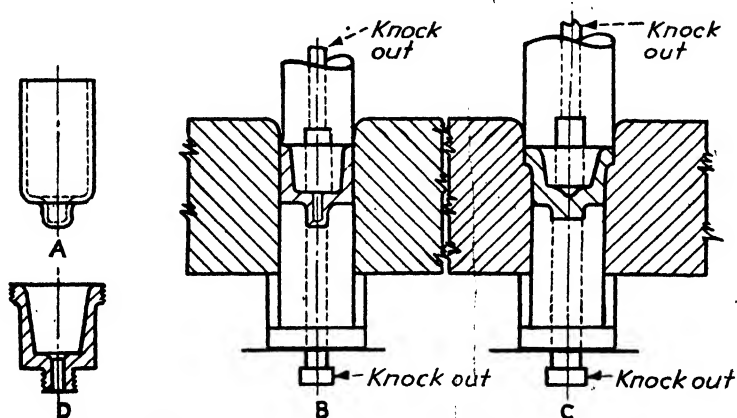
Fig. 285.—From the shell at *A* the finished oil cup at *D* is produced in a series of eight
cone-die operations.

Cone Dies.—Figure 285 shows five of the eight operations in
producing an oil cup in cone dies. These types of operations are
rather new and are good examples of thickening the walls of a drawn
shell by forced plastic flow. In this case the walls have been doubled
in thickness at some places.

At *A* the two-operation shell of $\frac{5}{64}$-in. soft brass is run through a
series of dies to thicken the walls and bottom. Sketches *B* and *C*
represent the fourth and fifth operations, respectively, and *D* shows
the finished oil cup, drilled and threaded.

These are practically swaging operations, and the work is ejected
by elevating an underslung ejector bar with the ram ascent, as illus-
trated in Fig. 259. Such dies must be of comparatively heavy con-
struction, and their interiors polished in a vertical direction. The dies

are all of similar design; each operation is another step in which the bottom and wall of the parts are gradually thickened. Annealing is necessary between operations.

The "Hump" Principle in Drawing and Forming.—Some of the things that seem puzzling to those who have not actually had to do them are how to bend sheet metal more than at a right angle, put initial tension in a flat spring or a clip, and give sharp corners to a drawn cup.

In ordinary practice, the sharpest corner will have an outside radius greater than the thickness of the metal. In both drawing and bending it is necessary to round the corner of the punch slightly; otherwise it would act as a blanking or a trimming punch in drawing and a cutoff punch in bending. Leaving the corner sharp in a bending or drawing die does not help, because the work "follows" the punch and would not fill in the sharp corner.

In thin metal, the taper of the cup and the radius at the corner are not so noticeable; but if the metal is, say, $\frac{1}{4}$ in. thick and the depth of the cup is less than half its diameter, then both the taper and the lack of a sharp corner are distinctly noticeable. For instance, a brake drum drawn in this manner would be useless. Additional drawing operations might help in ironing the drum into a shape more nearly round but because of the reasons given above would not sharpen the corner.

It is practically impossible to make an accurately round and straight-sided drum by drawing without applying a force that exceeds the elastic limit of the material, and this is seldom possible with a punching of this size. The trouble lies in the difference in the action of the material in drawing both with and across the grain. This difference is much more noticeable with bessemer steel than with open hearth; with high, or yellow, brass than with low, or red, brass.

Hump Principle Produces Sharp-cornered Shells.—To get a sharp corner it is necessary to resort to what may be called the "hump" method. The application of the hump method is analagous to that which a carpenter uses when he wants a tight joint between the ends of two boards. He cuts his fitting board a trifle long and bows it slightly to get it into place. After the center is brought down flat by nailing, the board ends are tight fits.

In drawing a brake drum, the faces of the punch and the die are so made as to make a concavity in the blank. This first-operation cup is then placed in a die that is the shape and size of the finished brake drum. This die has a heavy bottom to withstand the pressure. The punch is made to fit the inside tightly at the top, is straight, is flat

on the bottom, and has as sharp a corner as is possible without shaving the inside of the drum.

The diameter of the drawn drum, as measured along that of the hump or concavity, is greater than the flat diameter of the die. As the punch descends, it strikes the hump and flattens it. This, in turn, crowds the metal into the corner of the die with a force sufficiently great to cause plastic flow or cold forging. A practically sharp outside corner and straight sides are the result. Even this treatment will not make the drum uniformly round, and it is usual to take a light cut by turning or grinding for truing. This method is equally applicable to rectangular boxes, plates for push buttons, or any work where the metal can be so confined.
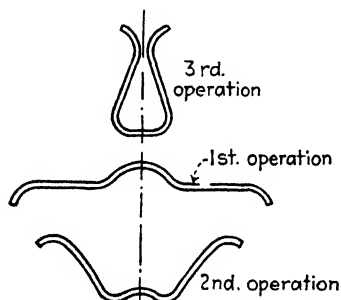
Fig. 286.   Fig. 287.

Fig. 286.—Hard-copper clip for a knife-blade switch.
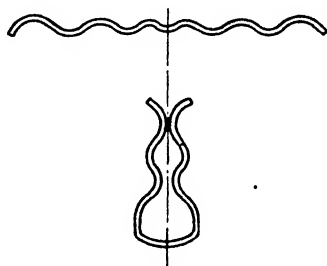
Fig. 287.—Spring clip for papers and magazines. In both articles the wings are brought in beyond the vertical by flattening the hump in the last operation.

An outstanding example of the hump method of bending may be observed in making the hard-copper spring clip used in the ordinary knife-blade switch. The operations necessary to bend the sides beyond the vertical are shown in Fig. 286. These operations are particularly useful with work of spring steel and phosphor bronze, where corner radii are necessarily large, and even then right-angle bends are difficult to make.

The hump method is not confined to drawn work. It is equally good for making odd shapes and bends. In Fig. 287 is a spring clip for holding papers and magazines in newsstands. The hump is of irregular shape and is flattened to bring the wings beyond the vertical for tension, the principle being the same as in the other examples.

Drawing Shells in Double-action Presses.—Figure 288 presents a rather unusual tool design for drawing several different shapes and depths of square shells, with round corners, in the same die.*

* This die design is used by permission of the Faries Manufacturing Company.

A cross section through one of the shells is seen around drawing punch *A* and within drawing ring *B*. Member *C* is a cast-steel

FIG. 288.—Double-action combination blanking die for drawing rectangular shells with round corners and different shapes around the top. It also draws various panel designs in the bottom. This is accomplished by reversing the die block and changing pads within the punch and die.

blank holder and blanking punch. The face of this punch is fitted with a separate cutting ring *D*, which also acts as a pressure pad

which holds the blank flat on the drawing ring and prevents wrinkles while the punch is drawing the blank down into the die. An adapter *E* is attached between the blank holder and the outer ram of a No. 3½*A* Bliss single-crank, double-action, toggle-drawing press. The adapter compensates for differences in the adjustments of the inner and outer rams and centers the blanking punch accurately over the die.

The unique feature in this die is that it not only blanks and draws a square shell, of the section shown in the illustration but, by turning the drawing ring *B* topside down, will also draw a straight shell without the 0.280*R*. Furthermore, by changing the removable circular pads *F* and *G* and substituting others, several different shapes can be drawn into the bottoms of the shells. Pad *G* registers at the maximum downstroke of the punch ram and spanks the bottoms of the shells.

This tool is a combination blanking and drawing die. The strip is fed through guides *H* and under the positively attached stripper plate *J*. The blanking die is built up of eight sections, as seen in the plan view. Knockout rod *K* is elevated when the rams ascend and removes the finished shell from the die. The work is stripped from the punch, in ascent, when its upper edge contacts with blank holder *C*. The uneven edge around the top of the shell is subsequently sheared off in a special trimming die.

Drawing Shells in Triple-action Presses.—This press is identical to the double-action types in all respects except that it employs a third ram operating upward through the bed of the press. The third punch indents, shears through, embosses, or otherwise operates on the face of a shell that has been blanked and drawn through by the double-action equipment.

When the drawing punch ascends, it carries up the completed shell until its edges contact the stripping edge under the drawing die. At this point the work is stripped off, while the punch and blank holder continue to ascend. Space is provided above the lower punch, when it withdraws, for ejecting the shell. Triple-action presses are not very common, because the necessity for using them seldom arises. Similar operations can be performed in single- or double-action dies, as shown in Figs. 267 and 288.

CHAPTER XXI

LOW-COST TOOLS FOR LIMITED PRODUCTION

Small Shops, New Industries, and Even Large Concerns Starting to Manufacture New Products Find Uses for These Specially Selected Examples of Low-cost Tools for New Products or Short Runs of Old Products

Introduction.—Radio sets, electric refrigerators, domestic stokers, air-conditioning units, and many other products have passed through stages where their manufacturers needed low-cost tooling because many changes in apparatus designs were involved. This process of evolution is going on continually in many lines, and the tool engineers responsible must be familiar with the principles of designing satisfactorily low-cost or temporary tooling as well as the high-production types that come later. Small shops have need continually for cheap tools that will not be an excessive burden on small-lot orders. The examples given here for progressive piercing, forming, and cutting-off tools, for adjustable die holders; and for tools to be used in vise or shaper are all practical examples of principles that have given good account of themselves in job-lot work.

Some of the cases cited, notably press jobs run in a shaper, are speedy and accurate enough for regular production of many small parts. A shaper can easily be considered as just another type of horizontal drawing press, and a large variety of small shells can be economically drawn, redrawn, and sized in this machine. Small shops that have no punch presses can do a considerable assortment of die jobs in a shaper.

Cheap Tools Easily Changed.—Before a new product has become standardized, innumerable changes in apparatus designs are always necessary. It is therefore a good policy to begin production with low-cost temporary tools and with only one operation performed in each. Then these simple low-cost tools can be changed without much expense.

Temporary press tools are single-station blanking, piercing, or forming dies without guide posts. A positive stripper plate can be used, or "sky-hook" ejectors attached on thin die blocks which can be easily worked out.

If piece-part holes are necessary, the holes are drilled through unbushed pack-casehardened drilling jigs, instead of using expensive

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piercing dies. Each forming operation is performed in a separate die. Effective alterations can then be made quickly in any of the tools .with least interference in the others.

Press Tools in a Shaper.—Several types of press tools can be operated successfully in an ordinary shaper. A shaper, with its ram, vise, and multitudinous adjustments, and especially the easy control of ram speed, makes it available for producing drawn shells. Figure 289 represents a die for drawing small brass shells.

Dies made for a shaper are very cheap and effective tools; the die holder *A* can be any suitable block of steel or cast iron picked up around
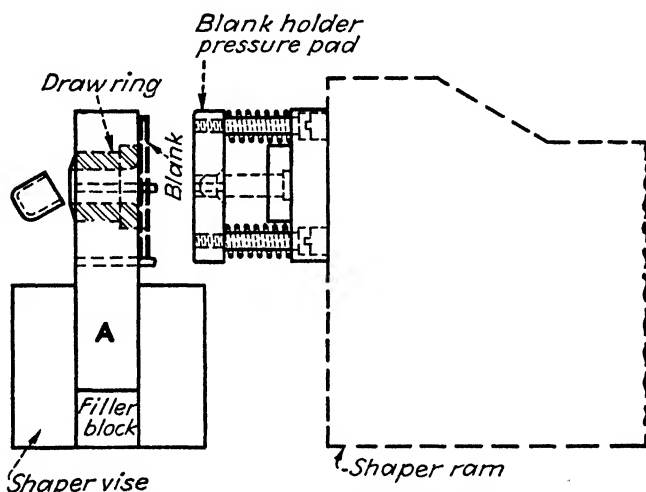
Fig. 289.—A shaper is a convenient machine upon which to set up certain types of press tools for simple die operations.

the shop. The thickness and height of die holder *A* must be sufficiently rigid to withstand the drawing pressure of the punch. No die sets are needed.

The many quick adjustments on a shaper that govern the length of stroke, die space, and vertical heights are found convenient for many varieties of press work. Another advantage is found in using vertical magazines for feeding cylindrical work into the dies. For sizing, burnishing, or redrawing shells, the magazine principle works out well.

Adjustable Die Holders.—Tool costs are reduced by using the substantial die holder shown in Fig. 290. Small shops favor this design. The material is either a steel casting or a steel forging. There are times when cheap and convenient press-tool equipment is wanted, and this die holder, together with its corresponding die, shown in

Fig. 291, is a suitable design. For still cheaper equipment, the guide posts can be omitted from the die.

The setup of this equipment is obvious from the sketches. The die can be clamped in the holder and positioned centrally. In operation, the tool is handled the same as if built into a conventional die set.

Several advantages are obtained from using this type of equipment. About three dozen of these adjustable die holders will take care of the
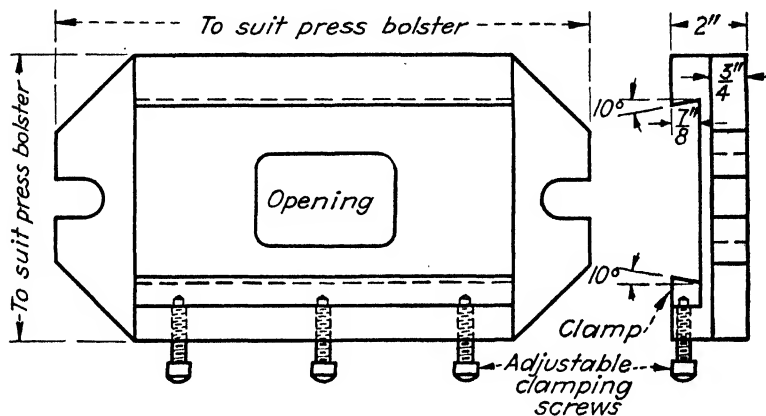
Fig. 290.
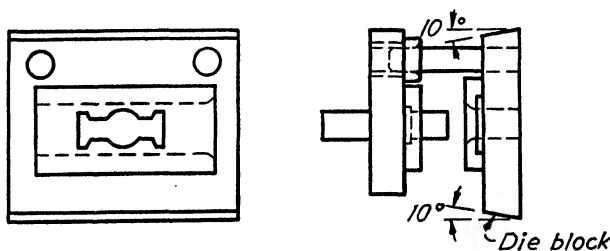
Fig. 291.

Figs. 290, 291.—About three dozen adjustable die holders will be found sufficient for using as many as three hundred dies as they are required.

output from several hundred dies. It is seldom necessary to remove the die holder from the press. The press tool is light and easy to construct and handle. About three widths of the dovetail-shaped tool-steel die sections are needed for each press size. The several cross-section widths are machine finished in lengths on a planer and then stocked. The stock keeper can cut off any required length for a new die block. Such tools as these require a minimum of storage space. Roughly estimated, they require about half the space of similar tools which are mounted in conventional die sets.

Inexpensive Die for Blanking Few Parts.—A temporary blanking die for cutting a few blanks cheaply is seen in Fig. 292. The die openings are section lined. These low-priced dies have been known to produce several thousands of good blanks.

Punch *A* is cut to line on a slightly tilted table, from die block *B*, on a diemakers' band-sawing machine; in this way the die clearance is obtained. The cutting face of the punch was the bottom of the die block before sawing; thus both the punch and the die clearance are
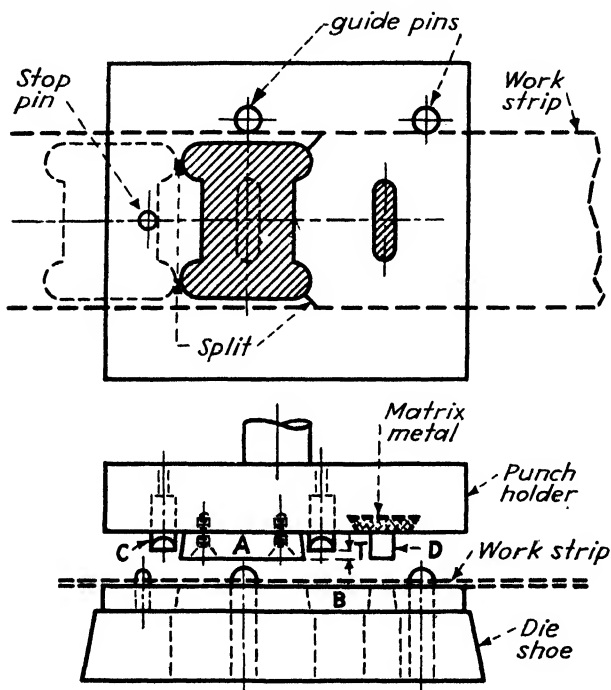
Fig. 292.—Temporary die for quick production of a limited number of blanks.

made in one cut. The material used is flat-ground tool-steel stock, ¼ in. thick. After smoothing the edges of the punch, it is then hardened and sheared through the die. The die is then hardened and face ground.

The punch and die are attached to the punch holder and shoe with flathead screws. No guide posts are used. Two or more scrap-splitting punches *C* are placed at advantageous places, depending on the shape of the blank. These punches sever the scrap frame by splitting it. It is therefore unnecessary to strip the scrap from the punch, and no stripper plate is necessary. Punch *D* in the first station

is stripped with a forked hand tool, if only a few blanks are made, or with a double key which is driven astraddle the punch. Dimension *T*, at the chisel edge of the scrap cutters, is equal to the material thickness. When only a few blanks are wanted, this die is used in a screw press or, for larger quantities, in a regular punch press.

Punch *D*, being too small for attaching with screws, is located by two dowel pins and anchored with Matrix Metal in a recess in the punch holder, as shown. Matrix Metal is sold under a trade name, it has a low melting point and is similar to type metal. It expands
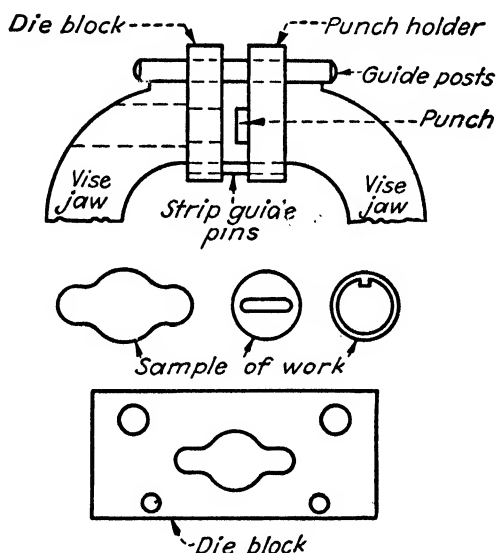
FIG. 293.—A bench vise provides the means for making quantities of small blanks from $\frac{1}{32}$- to $\frac{1}{16}$-in. sheet brass.

slightly when cooling. It is widely used in place of screws for anchoring punches and die parts. It is used even in high-grade tools and saves much time and expense by eliminating conventional fastenings.

These dies have capacities sufficient for producing about 7,500 blanks. They permit the use of stampings instead of castings in many cases when the sales of a product are small.

Cutting Blanks in a Bench Vise.—Small shops can substitute a bench vise for a punch press. Large quantities of useful blanks, such as designation plates, badges, washers, and tags, have been made from $\frac{1}{32}$- to $\frac{1}{16}$-in. gage brass by this method. Figure 293 shows the principle. The punch is sawed from $\frac{1}{4}$-in. ground tool-steel stock and file finished. Then the punch is drilled for one holding screw and two small dowel pins, hardened and tempered, and sheared into

the die. The die is subsequently filed out to allow proper punch clearance. This die has no stripper plate. For small quantities of blanks, the stock is stripped from the punch with a fork-shaped hand tool. For larger quantities, an open-side stripper plate is attached on the die, and the punch is made suitably longer.

Making 50 Blanks in One Cut.—Rectangular metal pieces are piled up one above the other, evened, and then clamped in a bench vise. Next, the pieces are soldered or welded together up the sides and corners. The top piece is then coppered and scribed with the shape of the blanks to be made. The assembly is then cut to line in a diemakers' band saw. For blanks $3/64$ in. thick, 50 or 60 duplicates can be made in one cut.

Pierce, Cut Off, Bend, and Form Consecutively.—Dies of these types are easy to design and build. With a little experienced forethought

Fig. 294.—A schematic layout of a die for piercing, cutting off, bending, and forming simultaneously.

they can be made to fabricate about 60 per cent of ordinary stampings. Most progressive dies are high-speed and accurate producers.

In Fig. 294 a tool design is shown for producing part A, one piece per press stroke. Incidentally, this operation is a clear case that shows the difference between bending and forming. The finished piece lies between the closed bending and forming members B and C. The work lies at an angle of 12 deg. from horizontal; this provides the necessary bending and ejection clearance for the end angles.

The high point on bending and forming die B is in the same horizontal plane with the surface of die block D. When the die block is ground for sharpening, an equal amount is ground from the underside of B to maintain relative heights. Stripper plate E is the positive-channel type.

Material strip *F* is fed against and within stop block *G* at the left, and the blanking length is cut at point *H* by the descent of punch *J*. The punch cuts out a length of waste $\frac{3}{16}$ in. long.

Punch *C*, in descent, contacts the cut blank instantly and bends and forms the free ends down into the die. A pointed pin *K* prevents the blank from "creeping" while the ends are bending and forming. The pin is backed up by a strong compression spring.

The press is used in a tilted position, and the finished work slides off in the rear, when the punch ascends. At *L* a side view of the cutting-off punch shows two heels ahead of the cutting blade that guides the punch into the die. Trimming edges of the blank to any desired shapes is done by adding openings in the die block under the stripper. Punches with backup heels are used for trimming.

Blanking and Forming in Soft-rubber Dies.—Strangely enough, soft rubber can easily cut and form thin metals if the right conditions are provided. Anyone can prove this statement in 5 min. in a bench vise with a piece of rubber gasket, a strip of metal, and a sharp-edged punch. This principle is not new; it has been used in a small way for several years.

The rubber is a heavy pad similar in consistency to bumper stock compression rubber, and is confined in a strong steel frame around the press ram. The blanking punch is hardened tool steel with sharp edges. For cutting thin blanks, the punch is placed face up on the press bolster, and the material strip is located over it. When the ram descends, the rubber pressure yields around the outline to be cut and the rubber is forced over the edges of the punch which cuts the blank. Steel blanks of 0.040 in. thicknesses can be cut.

In forming operations the edges of the punch are suitably rounded. This process is not so impractical as it may seem. Today, many large and small parts for airplanes and parts for apparatus undergoing changes are fabricated by this method. The idea has recently been expanded for quantity production.

Blanking and Forming Airplane Parts.—Because of many changes in the design of all metal transport and militamy planes, comparatively cheap and easy-to-change dies are necessary. When it is realized that an airplane requires thousands of intricate metal stampings and formed shapes, the economy of using low-cost tools is apparent. Rubber dies are susceptible to easy alterations when the parts are redesigned; they are also low in cost.

The blanking punch may be very large and require several lengths of strip steel for its cutting edges. The steel strips are bent to suit the outline of the blank. The strips are then sunk into a metal

supporting body. The punch is mounted, face up, on the bolster of a hydraulic press. On the face of the ram a strong steel frame is attached. The frame contains several sections of soft rubber. These sections make up a pad, or plane, of rubber parallel with the punch face. When the ram descends on a sheet of metal placed over the punch, the rubber compression acts as a cutting die around it. Continuing in descent, the rubber bulges around the punch and cuts a blank.

Forming operations are similarly performed, except that a forming punch is substituted in place of a cutting punch. If deeper indentations are needed in formed work at one or more places, extra-thick rubber mats are placed at those points before lowering the ram. This system of die construction, together with the details of operation, is known as the "Guerin process" and is a patented method of manufacture.

Adjustable Perforating and Shearing-off Dies.—Press tools with movable cutting members can produce a large range of blank sizes.
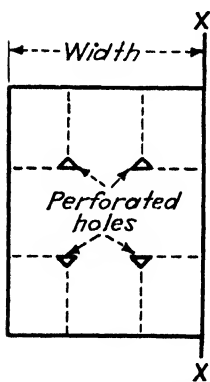
FIG. 295.—Shows a preparatory blank for a box, made in the adjustable die illustrated in Fig. 296.

They may also include pierced holes in scattered locations. A sheet-steel preparatory blank for a box is sketched in Fig. 295; it was cut in the adjustable die illustrated in Fig. 296. The preparatory blank is then corner notched in a universal die as shown in Fig. 297. It is then folded into a box as seen in Fig. 90. This blank and many others of different widths, lengths, combinations, and shapes of pierced holes can be similarly made. The limit for tool designs in this line is governed only by the ingenuity of the designer.

The shearing-off punch A, and die B, and spring-stripper plate C are positively attached, midway across the width of the die set. The stop block at the left slides in a slot. It is laterally adjustable toward either the right or the left. It is secured in place by a cap bolt, as shown. The position of the stop determines the desired widths of the sheared-off blanks. The blank is cut off on line X-X (Fig. 295).

On the right side of the shearing-off members are several adjustable punch and die blocks, which, like the stop, are retained by tongues or gibs underneath them which slide in slots. These blocks are also secured in place by cap bolts. The blocks can be designed of any size

or shape that suits the work in hand or any work likely to be run in the future. In these blocks are located the triangular punches and corresponding die openings for producing the blank shown in Fig. 295. The piercing punches and dies are removable, for interchanging other sizes.
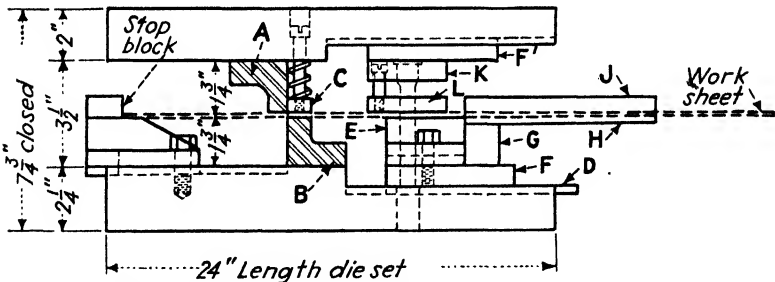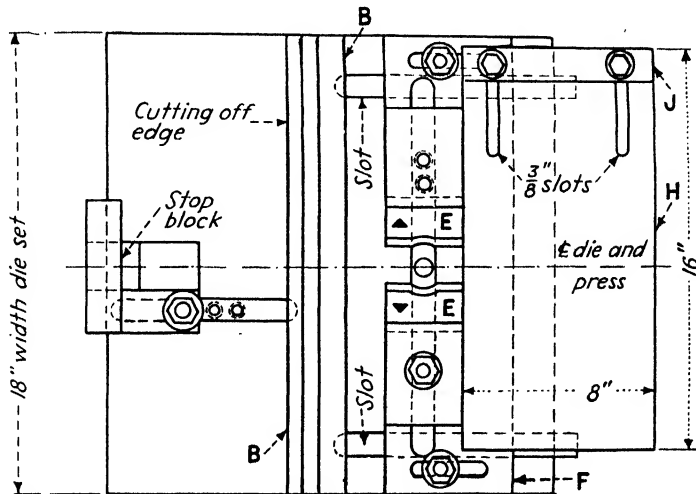
FIG. 296.—This die can be adjusted to perforate and cut off various sizes of blanks similar to Fig. 295. This blank is then corner notched, which makes a box blank (Fig. 297). The blank is next folded up into a box in an adjustable forming die. The corners are then spot-welded together.

An interesting feature consists in mounting die blocks E on plate F. Although plate F is also adjustable toward the right or left, blocks E are adjustable at right angles to the movements of F. Hence, the die openings and their corresponding punches, which are similarly mounted, can be placed in any position within range of the die-set area, at the right of the cutoff blades.

This two-way system of adjustment is the "keynote" principle in the success of adjustable tools.   It is a principle that can be applied in most adjustable dies for piercing, blanking, or forming.

Plate *F* carries block *G*, to which the stock table *H* is attached. At the rear of this stock table is the adjustable back gage *J*.   The back gage slides in slots and is secured by cap screws.   Position of the back
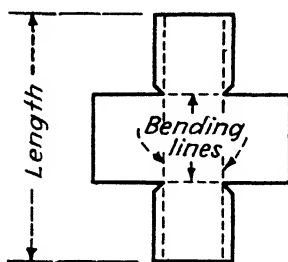
Fig. 297.—The preparatory blank with its four corners notched out. The blank is now ready to be folded into a box.

gage determines the length of blank.   Member *K* is an adjustable punch block; *L* is a spring-stripper plate attached to *K*; member *F'* is a plate for the lateral adjustment of the punches.

This tool is used in a tilted press; and after cutting off the blanks, punch *A*, continuing in descent, tips the blank down against the angle in front of the stop, thus freeing the work to slide off behind the press.

CHAPTER XXII

SPECIAL DIES AND NOVEL OPERATIONS

Trimming and Redrawing; Manufacturing Rim-fire Cartridges; Expansion
Drawing; Hydrostatic Dies; Rotary Swaging; Barrel Subpress Dies;
Miscellaneous Press Tools; Drawing of Aluminum: Curling and
Wiring

Trimming and Straightening Out a Flanged Shell.—Figure 298
illustrates the method of trimming, piercing, or notching the flange
of a shell and then straightening it out by redrawing. The original
shell was previously drawn, and flange *A* was purposely left for notch-
ing, as shown.
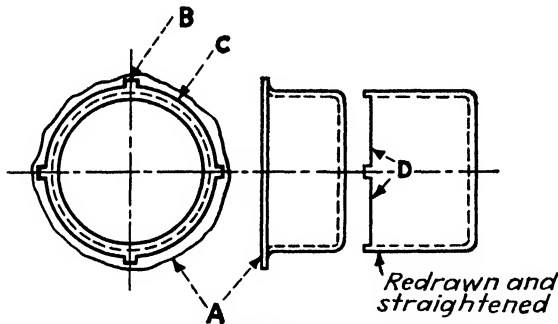
Fig. 298.—A flanged shell which is trimmed and notched within its flange. The flange
is then redrawn and the trimmed edges are straightened as at *D*.

The shell is placed in a trimming-die opening, closed end down.
The flange rests on the surface of the die. The punch carries a pilot
which fits the interior of the shell. The ram descends; the pilot enters
and "centers" the shell in the die. A cutting shoulder around the
punch and above the pilot notches and trims the flange on lines *B*
and *C*. The trimmed shell can be pushed through the die, or by
using a spring shedder in the die it can be ejected when the punch
ascends.

The next operation is simply to redraw the shell through another
die and thus straighten up its sides as seen at *D*. Shells trimmed in
this fashion are low in cost for certain types of work. Using this
method often avoids building or purchasing expensive trimming dies

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or using a special trimming press with which very few shops are provided.

Piercing, Trimming, Redrawing, and Stretching Out.—Another case of the trimming, redrawing, and straightening-out principle occurs in fabricating the peculiarly shaped shell shown in Fig. 299. In this part the straightening or stretching is done from inside the shell. The material is deep-drawing steel 0.025 in. gage, which is usually specified S.A.E. 1010. Three die operations are required to produce the piece.
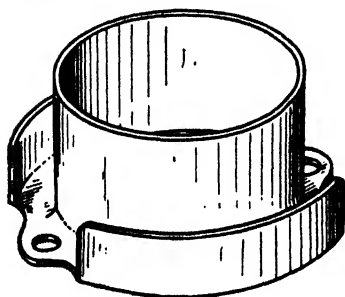
FIG. 299.—Three operations are needed to produce this coil mounting base.

The first operation is done in a combination blanking and drawing die, similar to one shown in Fig. 267. The shell body is drawn to the correct finished diameter but only $\frac{1}{2}$ in. deep (Fig. 301). The finished depth of $\frac{51}{64}$ in. will be obtained in the third operation by stretching out a perforated hole cut through the floor of the shell. The first-
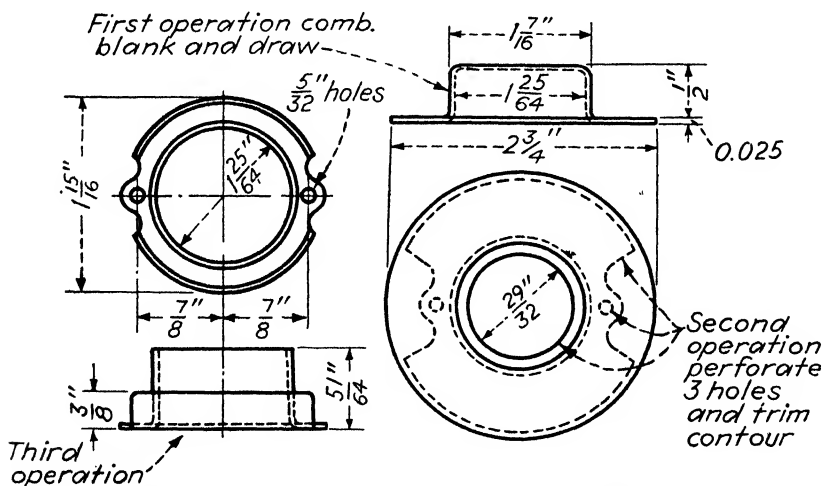
FIG. 300.
FIG. 301.

FIG. 300.—Dimensions are given on the third-operation part.
FIG. 301.—Solid lines indicate the first-operation stage, dotted lines the trimming and piercing done in the second operation; the finished depth of $\frac{51}{64}$ in. is obtained in the third operation.

operation die is set to leave a flange approximately $2\frac{3}{4}$ in. in diameter, which is later trimmed and reverse drawn $\frac{3}{8}$ in. high to form the outer-rim segments.

The second-operation die (Fig. 302) pierces two $\frac{5}{32}$-in. holes in the flange and a $2\frac{9}{32}$-in. hole in the bottom of the cup. This die also trims the contours around the holes in the flange and blanks the outer edges simultaneously. Two chisel cutters sever the scrap frame so that it falls away from the die in two pieces.
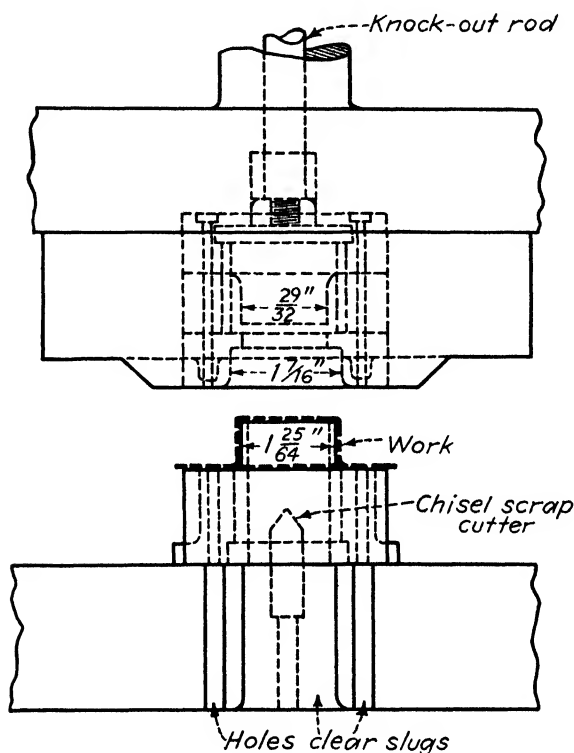
FIG. 302.—The original cup is drawn only $\frac{1}{2}$ in. deep, and in this second operation two mounting holes and the $2\frac{9}{32}$-in. holes are pierced; this leaves sufficient metal around the bottom of the cup for producing the $5\frac{1}{64}$-in. height, when straightened out by the die shown in Fig. 303.

The perforating, blanking, and trimming operations are performed at the same time. This means that the punches are at different levels, likewise the dies. No difficulties in grinding are involved, because the upper and lower dies are separate pieces and can be removed for grinding.

The stripper plate has a $1\frac{7}{16}$-in. diameter center hole clearing the body of the work and operated by a knockout rod through the punch stem. Three stripper bolts, not shown, keep the stripper plate in place.

The third, and final, die operation (Fig. 303) stretches out the annular rim left by the $^{29}\!/_{32}$-in. hole previously pierced. This die also draws up the outer-rim segments, as specified. Stretching the hole and throwing up its sides adds $^{19}\!/_{64}$ in. to the height of the shell and completes the $^{51}\!/_{64}$-in. dimension, as shown in Fig. 300. The fit between the punch and die must be close, because the piece must "bottom" on the die, and the opportunity is limited to iron out the crease where the bottom and sides of the shell join. It will be observed
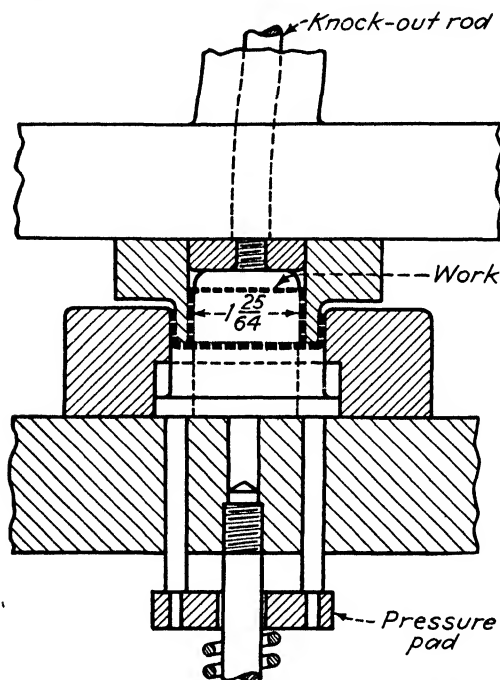
Fig. 303.—This die draws up the annular rim, throws up the sides of the shell to the correct finished height, and completes the piece as dimensioned in Fig. 300.

that the trimmed ears project beyond the outside diameter of the finished cup. This condition complicates the final redrawing die somewhat. Clearance slots must be provided for the ears. The part is carried up with the ram ascent. It is stripped from the punch by a pressure pad under the die and is finally ejected by the knockout rod with its attached pad.

Drawing and Annealing Ammunition Cartridges.—Cartridges made of brass stock, admiralty metal, or preferably "cartridge brass" are composed of 68 to 70 per cent of copper and 30 to 32 per cent of

zinc. "Pure Lake" or "Electroylic" grades of copper are specified 99.88 per cent pure, the remainder being small quantities of lead and iron. Zinc used is specified as "Grade A"; Brinell hardness for No. 12 Brown and Sharpe gage (0.0808-in.) brass strip should test between 50 and 65. Admiralty metal is practically the same composition as cartridge brass.

Rim-fire cartridges are commonly fabricated in a blanking and drawing die which produces six or eight shells per press stroke. The walls of the shells are drawn thinner than the original material thickness; therefore, the shell bottom is slightly thicker than its sides. Four redrawing operations are usually necessary, depending on the amount of shell-diameter reduction. The last operation consists of trimming off the mouth of the shell square. Annealing between draws is necessary to normalize most metals.

Annealing large quantities of small parts is done in a "tumbling barrel," or drum. The drum is a heat-resisting casting. A large number of holes are drilled through the walls to admit heat, but the holes are small enough to prevent the annealed parts from falling out.

The drum revolves and tumbles the work within the even heat of a closed annealing furnace. In the case of cartridge shells, they are usually dumped from the annealing drum into an acid washing solution contained in another revolving barrel. This removes the annealing scale which is "gritty" and very injurious to interiors of drawing dies.

After several redraws, the mouth ends of the shells become "ragged" and "wavy." This condition interferes with accurate automatic feeding in subsequent die operations. The shells are usually trimmed after the third or fourth redraws, depending, of course, upon their condition. Trimming is done on a small automatic lathe, equipped with automatic hopper feeds. The output is about 65 to 75 trimmed shells per minute.

Die operations for heading cartridge rims are shown by the principles set forth in Fig. 304. The shells are agitated in a hopper, not shown, which causes them to enter chute *D*. If the open end of a shell enters the chute, the shell is turned end for end by striking hook *E* in magazine *F*. The shell is caused to fall, closed end down, as desired.

This well-known principle is often employed for reversing pieces of work before they enter dies and special machines. For irregularly shaped pieces, the hook contour is shaped to suit indentations in the work. If a shell enters the magazine, closed end first, the head of the shell hits a point on the hook; the shell rebounds slightly and then

falls head first into the magazine in regular order.   Slide *G* pushes
the shells ahead against a stop and under the punch of the press tool.

The punch pilot enters the shell, and a shoulder on the punch
pushes the shell into the die.   When the shell protrudes through the
die, as seen at *A*, an anvil is advanced by a cam as shown at *B*.   Sketch
C shows the rim completed.   This operation is called "beading"
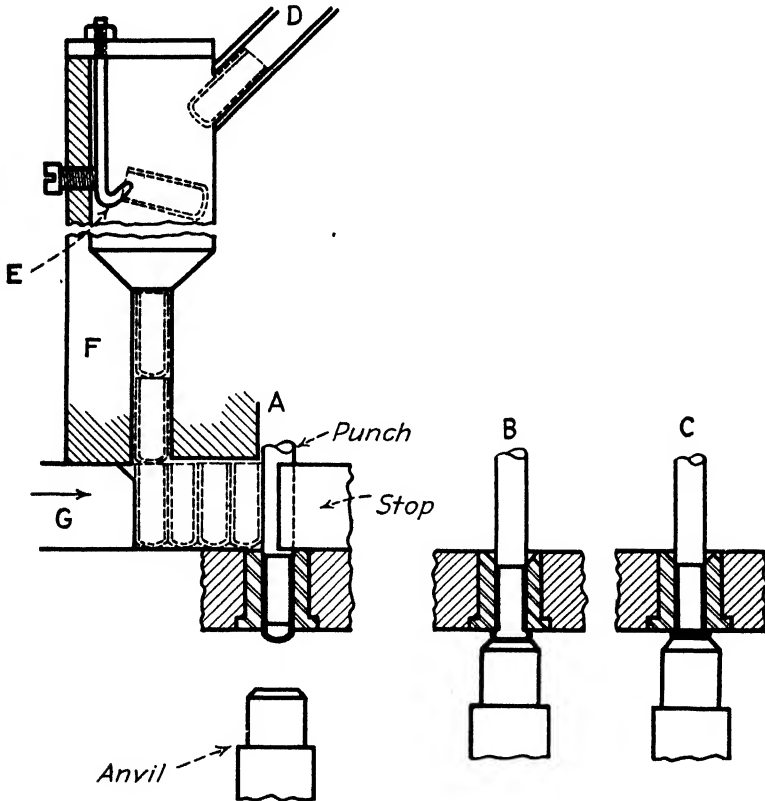
Fig. 304.—A shouldered punch at *A* pushes the shell partially through the die and
holds it there.   A cam-actuated anvil then advances from below and "beads" the
rim, as seen at *B* and *C*.

and is a principle frequently used in many other types of die-worked
parts.   After the rim has been formed, a quick fall in the cam causes
the anvil to recede suddenly, and the finished shell is pushed through
the die.

Small cartridge shells can also be blanked and drawn in multiple-
plunger eyelet machines, when annealing can be avoided by using
materials of sufficient ductility.   The metal will withstand more

frequent redraws without annealing, because the shells are worked continuously while warm. Continuous redrawing operations are more advantageous than operations done in separate tools, in which the metal becomes cold between draws.

Tricks in Die Design and Diemaking.—Strange to say, we frequently encounter very odd and interesting "tricks" in die work. Neither an expert tool engineer nor a diemaker can foresee them all. However, the mastery of all the tricks, if that were possible, constitutes part of the knowledge required of a journeyman diemaker. Sometimes these difficulties arise in work that otherwise seems very simple.
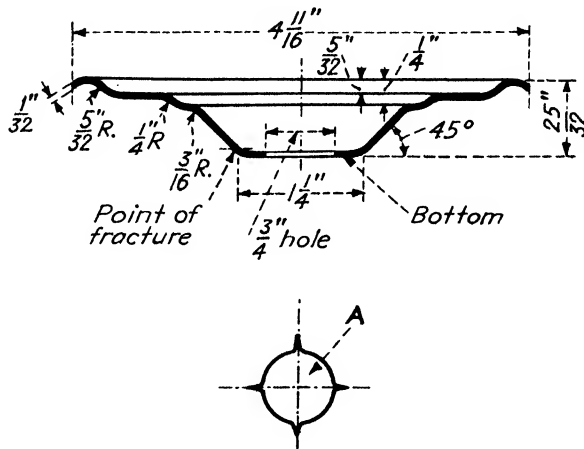
FIG. 305.—In drawing shallow work of this type, it was found that several tricks must be resorted to in order to produce perfect work.

A case in point is shown in the circular cover represented by Fig. 305. The material is 0.032-in. thick deep-drawing steel. The usual inverted type of combination blanking and drawing die was made, and there was no question that it would draw the work correctly in one operation. However, it failed at first. The apparent difficulties seemed to be the attempt to draw a shallow cover, of thin material and with practically sharp corners on the nose of the drawing punch.

It was found that when the ¾-in. diameter central hole was omitted, the bottom of the work fractured halfway around at the point indicated, and sometimes these bottoms came off entirely.

On the other hand, if the central hole was perforated before the draw, the fractures then appeared in four places around the hole similarly as shown at *A*. If the hole was perforated at the ⁵⁄₃₂- or the ¼-in. drawing levels, it became extremely distorted by the remainder of the drawing operation.

It was finally determined by experiment that if the hole was perforated when the bottom of the cover was drawn within $\frac{1}{16}$ in. of its finished size, the side fractures disappeared, but the finished hole, although a true circle and without fractures, was drawn $\frac{1}{32}$ in. over-size. The piercing members were then changed to perforate the hole sufficiently undersize so that the completed hole would be drawn to size.
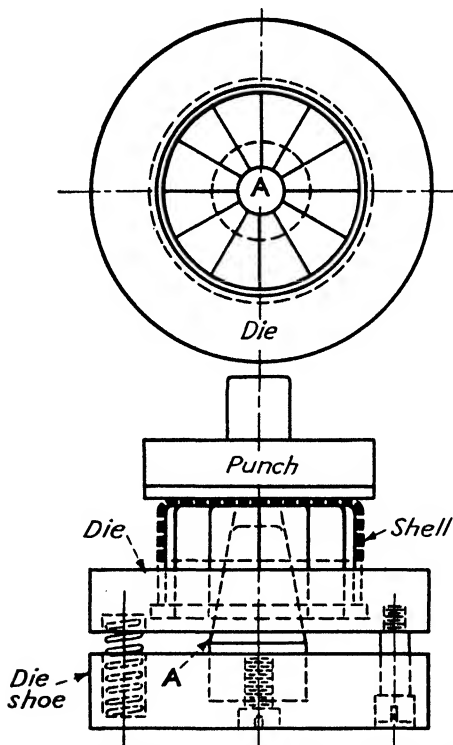
FIG. 306.—An expanding or stretching die used for flattening the waved surface across the bottom of large shell diameters. The radii of the arc segments in the die form a complete circle when expanded within the shell.

The size and shape of the hole were unimportant, but it was neces-sary that it appear true in shape and approximately to size; otherwise a second operation for shaving it would have been necessary. These conditions indicate the necessity of carefully analyzing just what occurs in the work at each stage, in the movement of a press ram.

Expanding or Stretching Dies.—Drawn shells of thin materials and large diameters sometimes have waved, uneven, or bulged bottoms. This difficulty may be due to using waved stock or faulty drawing dies.

A corrective die that flattens the bottoms by expanding or stretching the shell is represented in Fig. 306.

The die is composed of 12 equal segments. A tapered hole through the center of the die admits the nose of a positively attached tapered stud A. The stud is "bedded" in the die shoe. The die is mounted over the shoe and on compression springs, as shown. The punch is
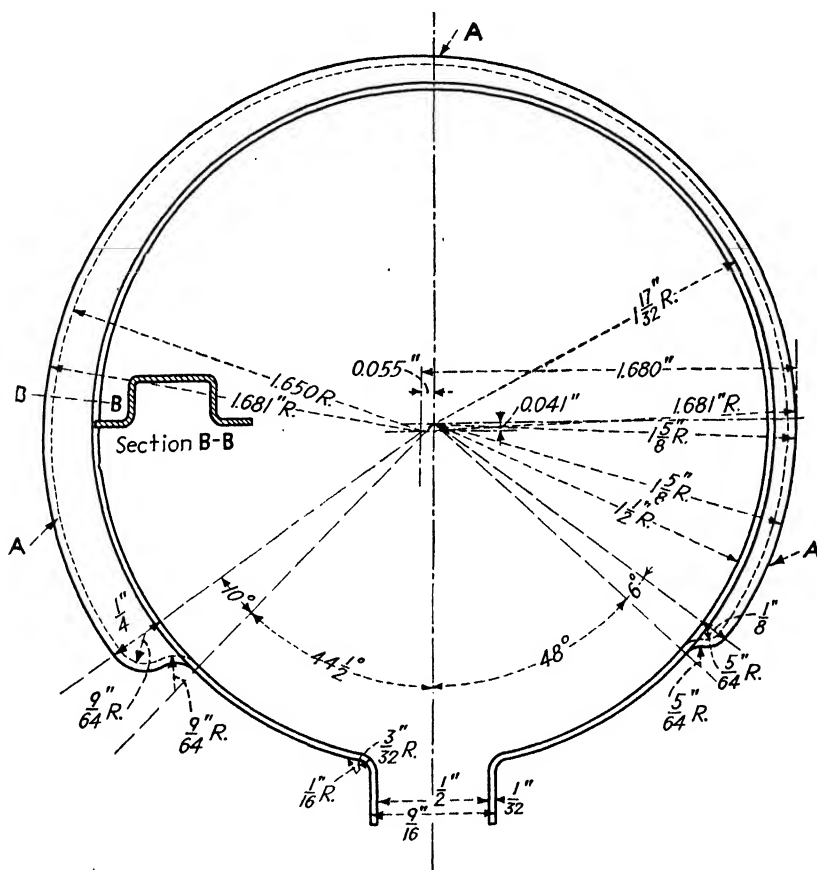
FIG. 307.—A brass collar with an expanded eccentric segment.

simply a planishing block. The shell is placed over the die, and the punch in descent expands the die segments around A. This action stretches the shell and flattens the bottom. The amount of stretch is controlled by a positive stop at maximum ram descent.

A coiled tension spring, not shown, surrounds the segments and closes them to a normal position, when the ram ascends, for removing

Fig. 308.—A closing and expanding die for drawing an internal eccentric segment.

a shell and for placing another. There is a possibility in using such dies for sizing shells that have been drawn slightly undersize.

Combination Closing and Expanding Dies.—Figure 307 represents a brass strap collar which has a bulged eccentric sector *A*. The bulged sector was drawn or stretched to size in the closing and expanding die illustrated in Fig. 308.

This die, and its operation, is an example of bulging or stretching a part mechanically instead of hydrostatically. The part could have been produced in a well-designed hydrostatic die by using a forced pressure of oil or fluids but at considerable loss of speed and output.

The center of the die is built up of eight internal sections. Four equal sections are as seen at *A*, and four equal sections, each larger than *A*, are represented at *B*. The inside contour of the bulge to be produced is worked out annularly around three of these sectors. The sections are interlocked in sliding fits, and a tapered entering hole is provided at their centers.

Four equal sectors *C* surround the center of the die. The outside contour of the bulge to be produced is worked out annularly within three of these sectors. The fourth sector, shown in front of the die, contains a channel that clears the protruding ends of the collar. When the sectors are closed, the shapes worked out within them conform with the outside contour of the finished work. Four internal compression springs are used for separating the inner and outer sections. When the ram is up, the springs cause the center blocks to collapse and the outer blocks to separate. This allows sufficient clearances for removing the work and space for inserting a new blank.

The blank, previously formed in circular shape, as described under Fig. 225, has two protruding ends. Using the ends for a handle, it is placed around the collapsed center blocks. When the ram descends, stud *D* expands the center blocks. At the same time, punch *E* forces the outer blocks to close together. The ram, continuing in descent, forces the inner and outer blocks to meet, with the work between them, and draws the bulge. Next, the ram ascends; the blocks recede; and the work can be removed.

The success of this tool depends upon designing the angles on the center blocks so that when the die is expanded, there will be no open spaces or steps in the periphery.

HYDROSTATIC DIES

Introduction.—The operation of hydraulic, or fluid, dies is based on a practical application of the well-known principle in hydrostatics

that pressure exerted on any part of the surface of a confined liquid is instantly transmitted undiminished to every part of the liquid.

Hydraulic die work originally meant expanding shells in a closed die by fluid forced into the shell with a hydraulic pump. More modern practice, especially for small work, is to use a press with a long stroke and of sufficient power to exert a pressure of between 1,200 and 3,000 lb. per square inch. The die is secured on the press bolster plate as usual, and the fluid, which is ordinary cutting compound, is introduced into the open top of the shell.

An Expanding Punch of Water.—The shell is held securely within the closed sections of a split die. When the press is tripped, a close-fitted punch descends into the mouth of the shell. Water being incompressible and the walls of the die sections strong, one of two things must happen. Either the shell must be pushed down into the die the same distance the punch entered, or the water must "blow out" the wall of the shell. If the shell rests upon the bottom of the die, the water pressure set up by the ram must escape, and in following the path of least resistance it expands the shell within the die walls. If there were no chance for shell expansion in any direction, the effect would be almost like bringing the punch down against solid metal.

The conditions outlined above illustrate the ordinary types of work done with hydraulic dies. Both hydraulic and hydrostatic work have the advantage that only a single die, the interior of which is finished to the shape desired, is necessary. In bending or twisting, the work is done by applying pressure against the inner surface of the bottom of the shell, and the work is pushed around one or more bends or turns provided in the die. Of course, success depends upon the thickness of the metal and the annealed condition of the shell material.

In simple bulging operations the bottom of the shell rests against the floor of the die, and the top is inclosed in a neck the size of the original shell. When the punch descends into the neck of the shell, the fluid pressure expands the work in all unconfined directions. This expansion continues until the shell walls are solidly against the inner die at every point. There are instances, such as the elbows of certain musical instruments, where both bending and expanding are necessary, but the principle of operation is the same.

Bursting Shells.—To ascertain just how far an operation can be carried, we must "burst" the bottoms out of a few shells or "blow out" their sides. This is necessary only when the first setup is made. After the punch-pressure depth has been found, it is scribed on the punch as a guide for future operations. Of course, if the next lot of

shells have different physical properties or the annealing is not uniform, the same troubles will be encountered as in redrawing shells in ordinary dies.

As in every other art, hydrostatic work has troublesome conditions which must be foreseen. It is evident that to set the punch for the final operation at just the exact height to impress the metal against all the surfaces within the die and not come down hard enough to injure the press requires care, because safety features are difficult to install. In work where a small mark on the bottom is permissible, a vent hole is provided through the die at the point where the bottom of the shell touches. Use of a vent depends on the thickness of the metal used. The hole diameter should be $\frac{3}{16}$ of the shell diameter at the point. Under excessive pressure, the bottom of the shell will blow out through the hole, which acts as a safety valve. Care should be taken that the vent hole points in a safe direction.

Powerful Latch Needed.—In designing hydraulic dies where closed-bottom shells are used, the finished form is first worked out in two halves, much like a drop-forging die. The difference is that the halves of hydraulic dies must be hinged and provided with a latching device that, although rapid to operate, will hold so tightly that an internal pressure of 5,000 lb. per square inch will not force the halves apart enough to mark the shell. Above the formed body there must be a long neck the diameter of the outside of the shell. Whether the work is bending or bulging or both, the neck is necessarily drawn farther down into the die when the shell expands. The neck of the die must be long enough to allow for this recession of metal, plus from one-half to one diameter of the punch. The shell, likewise, must be of sufficient length to allow for this recession while the body is expanding. The punch should fit within the neck of the shell closely and enter at least half its diameter before expansion begins.

A design for a fluid die of the type just described is shown in Fig. 309. The shell has been inserted between the closed halves of the die and contains the fluid to be used; the punch is ready to descend and expand the shell. Embossed designs can also be done by this method. The metal enters the letters and lines of the design readily and makes a very satisfactory job.

The material used is high brass 0.050 in. thick. Five drawing operations are necessary to finish the shell which is 9 in. long. The first draw makes a cup $3\frac{3}{8}$ in. in diameter by $2\frac{5}{16}$ in. deep. The second, or first redraw, makes a $2\frac{3}{4}$- by $3\frac{1}{4}$-in. cup. The second and third redraws form $2\frac{1}{8}$- by $4\frac{9}{16}$-in. and $1\frac{11}{16}$- by 6-in. cups, respectively. The fourth and final redraw is $1\frac{1}{4}$ in. in diameter by

9 in. long. The wall thickness of the finished shell is 0.040 in. This leaves a bottom slightly thicker than the sides. Deep redrawing operations are done on a rack-and-pinion redrawing press.

Using Differential Pressures.—When using a hydraulic press for expanding and bending simultaneously, it is necessary to use differential pressures. A piston must be provided to push the shell down into the die as it bends or expands, and at the same time sufficient
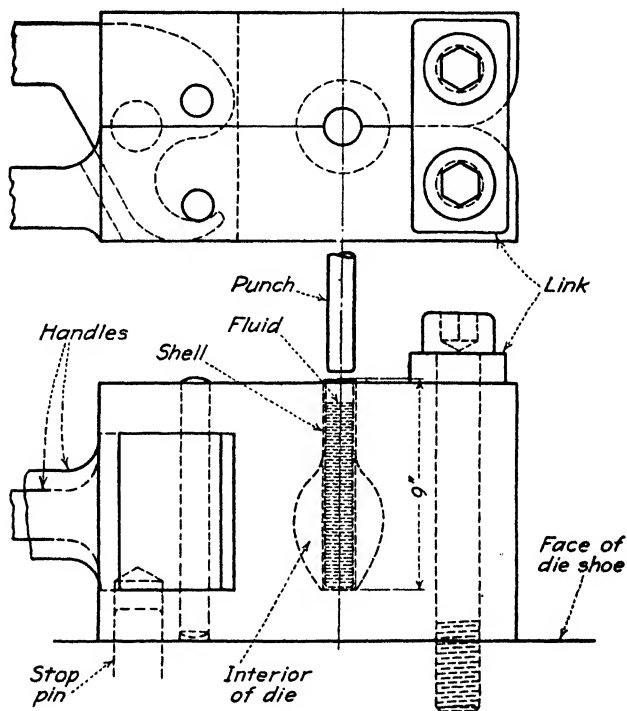
Fig. 309.—A heavy latching device must be applied to the hinges of fluid dies so that the halves of the tool will not spread under heavy hydraulic pressure and mark the work.

pressure must be maintained inside the shell either to prevent its collapsing while bending or to expand it. When the piston pressure is too great the shell will buckle or collapse, whereas too great an internal pressure will cause the bottom of the shell to burst. The rate of water admission must also be controlled.

Expanding Artificial Limbs.—Hydraulic dies for twisting and bending long tubes and for expanding parts such as artificial limbs must necessarily be designed horizontally. For artificial legs, duralumin or magnesium alloys are used to obtain light weight. The

thinnest tube that will withstand the strains is used. The difference in diameters between the ankle and calf is so great that a tube of the ankle size cannot be expanded enough to meet the requirements of the calf. Therefore, the usual practice is reversed, and a tube of the calf diameter is used and spun down roughly, before expanding, to conform to different diameters of the leg. City water pressure is introduced at one end and is closed when the form has been filled. In this case many different sizes and lengths of legs are necessary, and the press must be very wide and heavy to accommodate the variety.
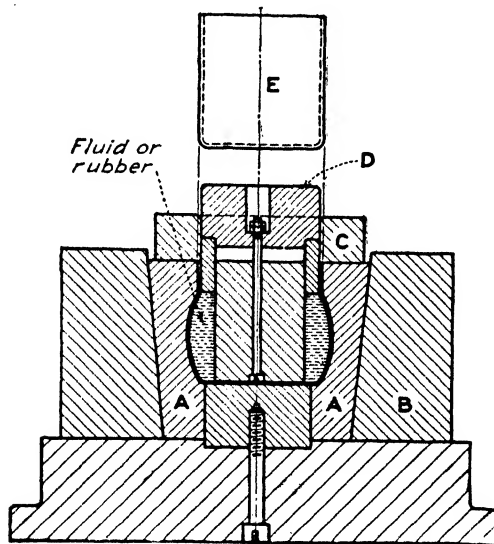
Fig. 310.—Four tapered die segments *A*, of circular contour, open outward when raised, to release a shell that has been bulged by fluid or rubber.

Expanding Shells with Soft Rubber.—Grease or wax is often substituted for fluid in certain types of small work. In other cases, soft rubber is used. An illustration of an expanding die in which either a fluid or soft rubber can be used is given in Fig. 310. This die is used in a double-action press. The die itself is composed of four tapered segments *A* which can be closed together within ring *B*. The blankholder ram is attached to ring *C* and descends first, and this action closes the die segments. The expanding punch *D* follows, compresses the fluid or rubber, and completes the operation. When soft rubber is used, it is of tubular form and is stretched by forcing it on to the punch. Above the die is a sketch of the drawn shell *E*, as it appears before expanding.

Rotary Swaging.—The cross-section view of a rotary swaging head (Fig. 311) shows one method for tapering the end of a light metal tube. Longer tapers are similarly swaged on golf-club shafts.

Bushing *A* is provided with a tapered center hole which is highly polished. The head and bushing *A* revolve together at high speed. The work *B* is a tube. It is placed over the tapered arbor *C* and registers against shoulder *D*. It is then slowly advanced into the bushing, either by hand or by a slide operated by a cam in an automatic machine. An expansion feature in the arbor prevents the tube and bushing from revolving together. Continuing to advance the arbor, the revolving bushing gradually closes the wall of the tube on to the tapered end. When the arbor point stops against button *E*, the operation has been completed, and the arbor and work are withdrawn.
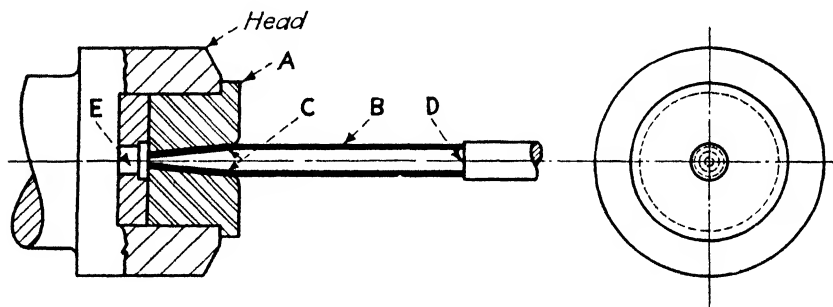
Fig. 311.—Rotary head for swaging tapers on the ends of tubes.

These operations slightly increase the over-all length of the work. It is very similar to spinning operations and is attained by a forced plastic flow within the metal part. Various types of **rotary swaging** machines are made commercially for producing such operations.

BARREL SUBPRESS DIES

Arch and Overhang Subpress Dies.—These dies, for producing high-precision work, were one of the early developments of the Waltham Watch Company. The purpose is to maintain a permanent alignment between the cutting punches and the dies.

Figure 312, drawn to the scale appearing in the figure, is of standard size and design. The proportions given can be followed for other sizes. This drawing sets forth both the arch and the overhang types. The neck for the overhang design is represented by the dotted section lines in the plan. The arch design is obviously stronger but will admit only a work strip of less width than the least distance across the arched opening. The overhang type is used for wider strips and to accommodate multiple rows of blanks.

The adjusting ring, omitted in the plan to show the tapered Babbitt-metal lining around the plunger, is screwed down when necessary to compensate for wear. Because the Babbitt metal is forced down evenly by the ring after adjustment, the plunger always remains "centered" by the taper. The drawing represents the
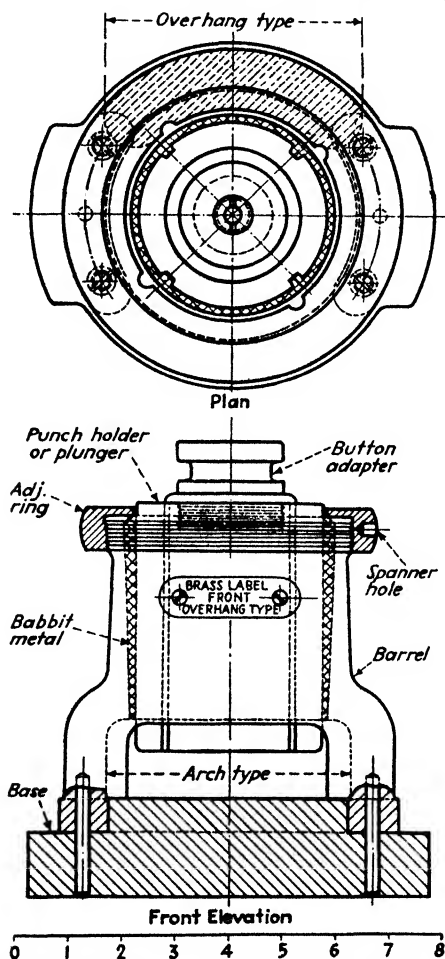
FIG. 312.—Standard die set of the arch and overhang types of barrel subpresses.

cylindrical types of subpresses. The one shown is a "blank set" ready for machining the plunger face for attaching a die. The barrel is usually of cast iron or semisteel, and all other parts are machinery steel. The button adapter fits into a T-slot in the punch-press ram and compensates for all the possible variations due to a worn or loose ram slide.
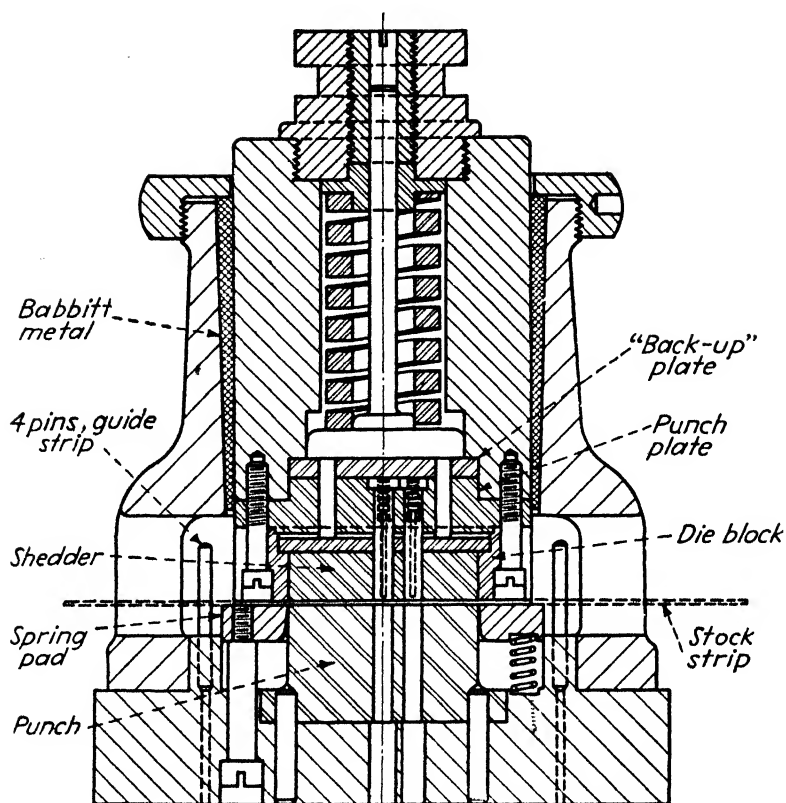
Section **B-B**

Fig. 313.—Sectional view through an inverted compound die of barrel-type subpress construction.

Scrap strip design

Fig. 314.

$\frac{1}{4}''$ S.F.
2 holes

B 22°

30°

$\frac{1}{4}''$ dowels
2 holes

$\frac{5}{16}''$ For screws 4 holes

$3\frac{7}{16}''$

$2\frac{1}{4}''$ S.F.

$\frac{3}{16}''$

$\frac{19}{32}''$

$\frac{21}{64}''$

$\frac{5}{64}''$

$2\frac{11}{16}''$

$\frac{9}{16}''$

G

G

Insert
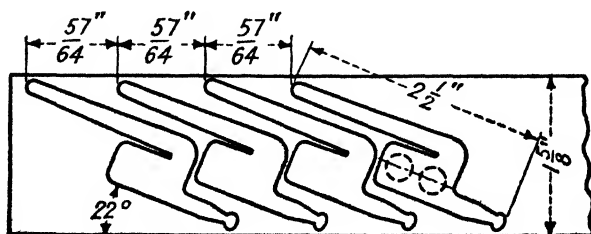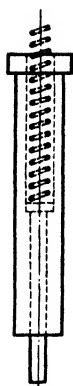
Punch and Push-off Pin
2- T.S. H. & G.

Fig. 315.

Punch plate T.S. H. & G.

Fig. 316.

0.040″ saw slot

Clear 4 splines

A 22°

A

30°

0.250″ diam.
dowels, 2 holes

$3\frac{7}{16}''$

$2\frac{11}{16}''$ fit punch plate

G

Fit shedder

$\frac{1}{16}''$

G

Die block T.S. H. & G.

Section A-A
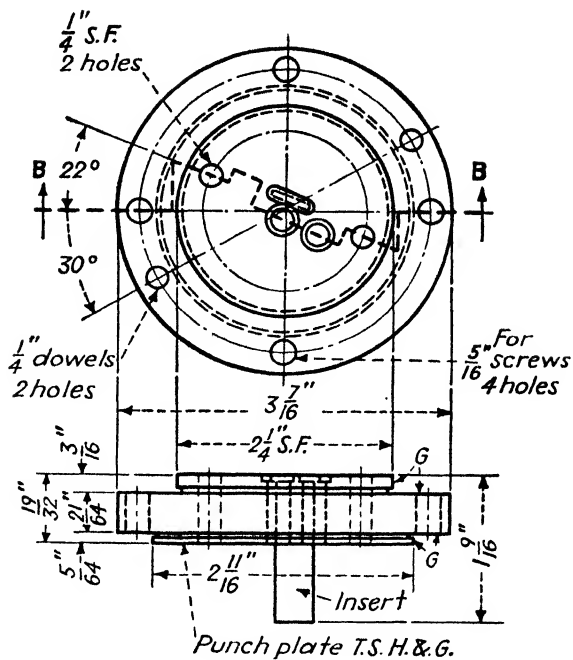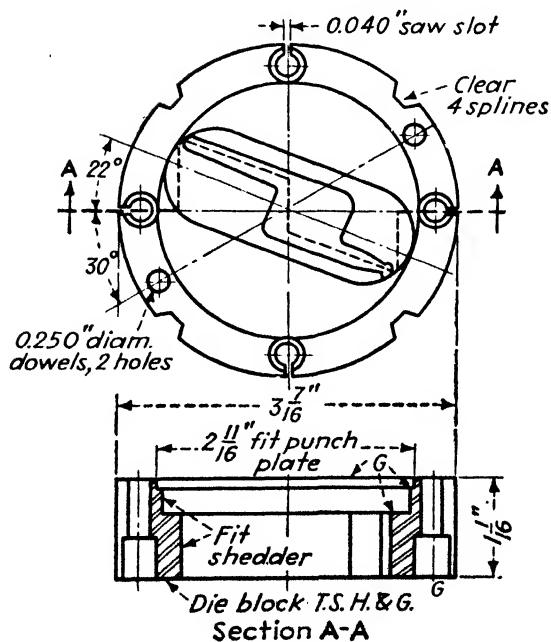
Fig. 317.

Compound Subpress Dies.—These dies are employed in producing small blanks of great accuracy, such as the working parts in watches, meters, adding machines, and high-precision mechanisms.   The usual design and drafting technique for an assembled compound subpress die is presented in Fig. 313.   The scrap-strip development for the
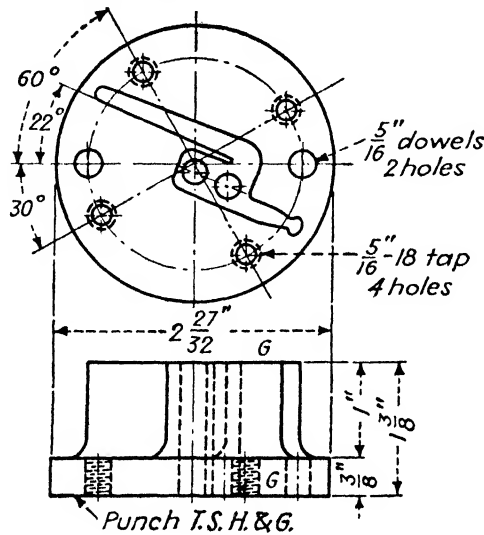
Fig. 318.
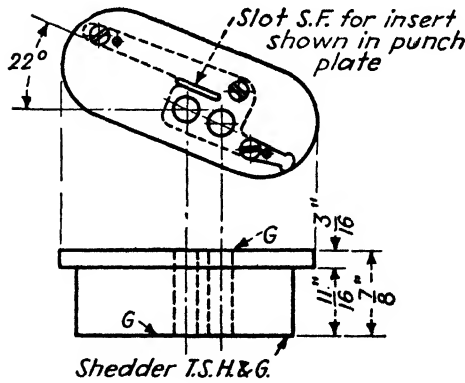
Fig. 319.

blanks is given in Fig. 314.   The blank is of light-gage nickel silver and is a precision contact spring used in high-grade telephone equipment.   Sizes of the springs must be accurately maintained to suit subsequent operations in assembling fixtures.

This tool is an inverted compound die.   The blanking punch is aligned under the die-block opening as seen in the assembled view.

The slugs from the two mounting holes in the spring are cut and forced out through the die openings in the face of the blanking punch. The holes are pierced by punches in each of which a spring push-off pin is provided. This precaution prevents the slugs from following up with the punches in ascent. One of the punches is detailed with its push-off pin in Fig. 315.

By a perusal of the die parts named in Fig. 313, in connection with the five detailed parts shown in Figs. 316 to 320 inclusive, the design and operation of the assembled tool are readily understood. The

Spring Pad, 1-C.R.S.
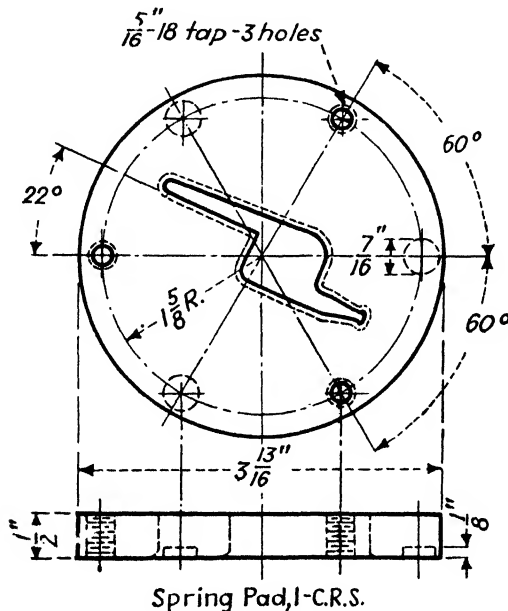
F<small>IG</small>. 320.

sectional view through the assembly (Fig. 313) is taken through all the individual parts, approximately on line *B-B*, shown across the punch plate in Fig. 316.

Piercing Dies.—A typical design for a perforating die is given in four views (Fig. 321). One method for giving the jig-boring dimensions is also shown. In Fig. 322 are three views of the work. The piece is 0.042-in. gage deep-drawing steel, previously blanked, drawn, and trimmed, preparatory for piercing the 19 holes.

The die set, with guide posts at diagonal corners, gives the best alignment of punches and dies for a comparatively large die of this type. All the round holes in the die blocks are "bushed." The out-
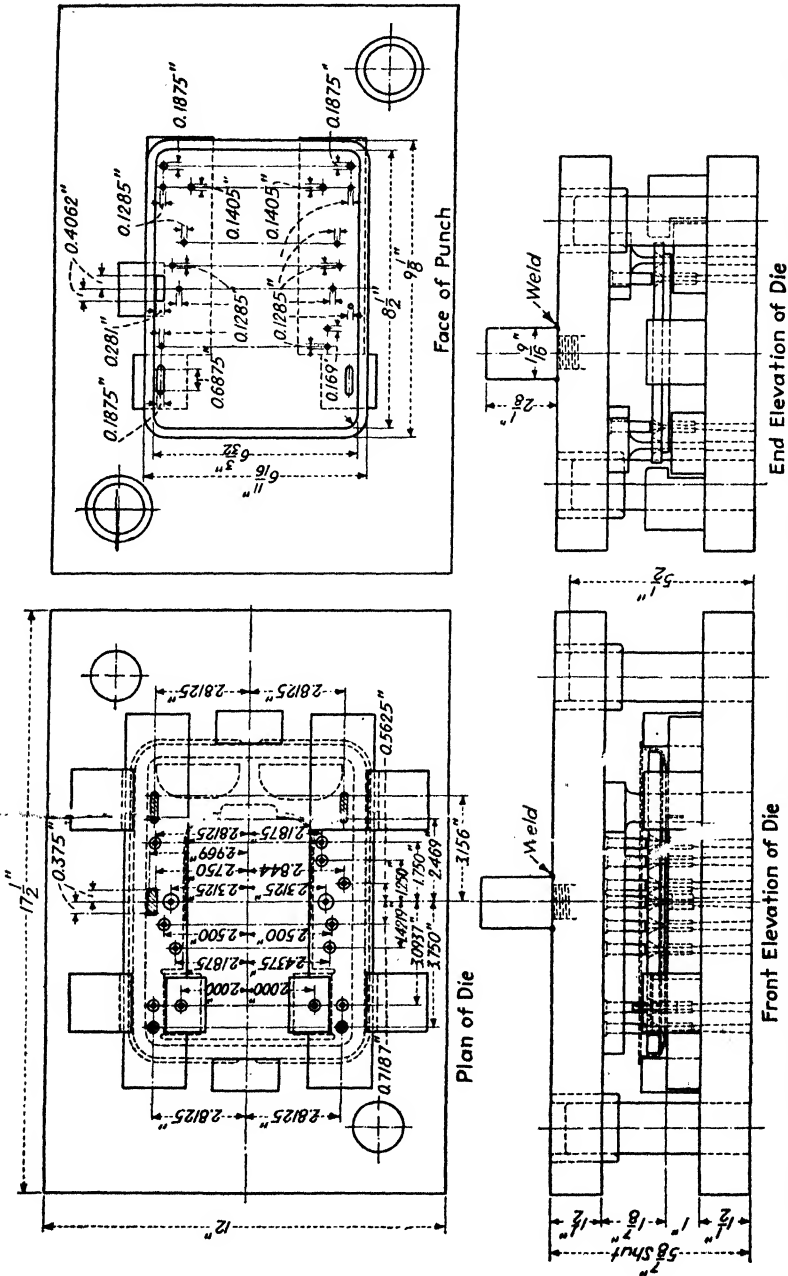
Fig. 321.—A typical piercing die equipped with a spring-pad stripper plate for piercing 19 holes in a steel mounting base.

side diameters of the bushings are the same as the body diameters of their corresponding punches. This makes possible the clamping together of the punch plates and die blocks for boring all the holes simultaneously. In this case hardened bushings for the die holes make it possible to use a cold-rolled steel die block.

None of the punches is "bushed" through the stripper plate. This is because none of the punch points is less in diameter, than the stock thickness. Otherwise, shouldered bushings would have been used to
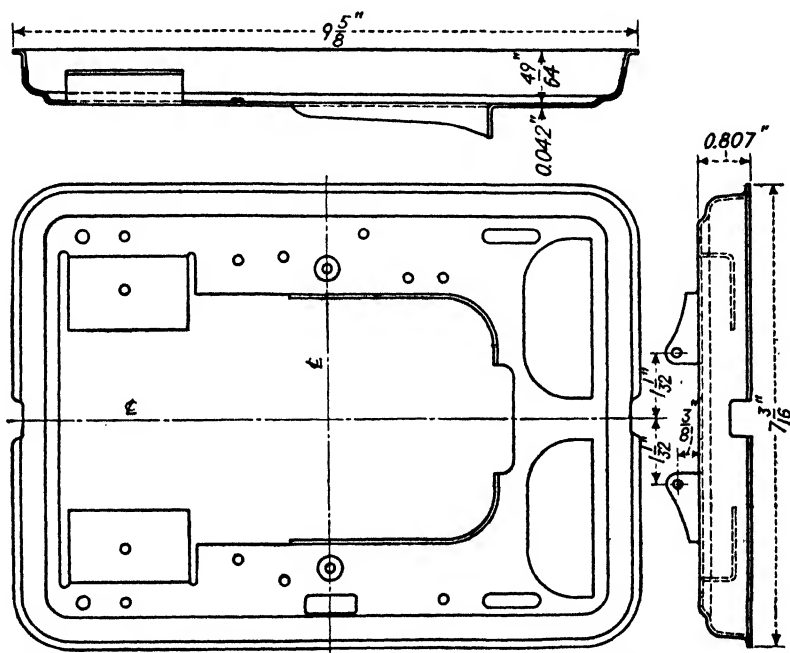
Fig. 322.—Illustration of the finished work produced in the piercing die shown in Fig. 321.

guide small round punch points through the stripper plate. It would then have been necessary to attach pins in the punch holder long enough to pass down through guide bushings in the stripper plate.

The die set is commercial. It is an all-steel built-up precision set, and the punch shank is screwed into the punch holder and welded. The cost of tool steel and hardening has been held at a minimum. Only the piercing punches and six other small cutting members are of tool steel. All the other parts are of cold-rolled or machinery steel. The six locating gage blocks can be pack casehardened for wear, if necessary.

A Useful Compound Die.—Compound dies of the design presented in Fig. 323 are useful for piercing and blanking parts from thin strips of metals and nonmetallic materials.

For strip stock the slotted guides *A* and a stop pin are used. For cutting mica, leather, and materials that cannot be obtained in strips, *the guides are removed. The sheet is then blanked promiscuously, using the stop pin as a guide that gages in previously cut holes.* Paper and cardboard can be cut without hardening the punch and die.
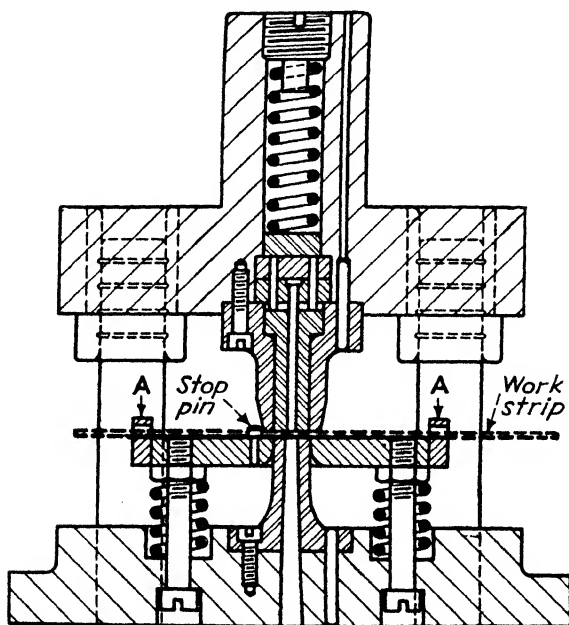
Fig. 323.—Typical compound die for piercing and blanking light gage metals, non-metallic strips, and sheet mica.

It is noticed that spiral oil grooves around the guide posts are not used. Annular oil grooves cut within the guide bushings are substituted. This method confines the oil within the bushings where lubrication is needed and prevents the oil from running down the posts.

For dies that must be ground, the over-all length of guide posts is made ½ in. less than the closed height of the tool. It is best that the ends of the posts do not leave the guide bushings at the highest point of the ram ascent. This prevents side movements in the ram slide, in descent, where the posts are too short to remain in the bushings

when the ram is up. It also confines the oil within the bushings. Extra-long or shouldered bushings are sometimes specified to get these results.

Cutting Off, Trimming, and Forming Progressively.—In producing parts similar to A (Fig. 324) and using a "cut and carry" die, it is often difficult to cut off the piece and trim semicircle B without leaving a flat or waste.
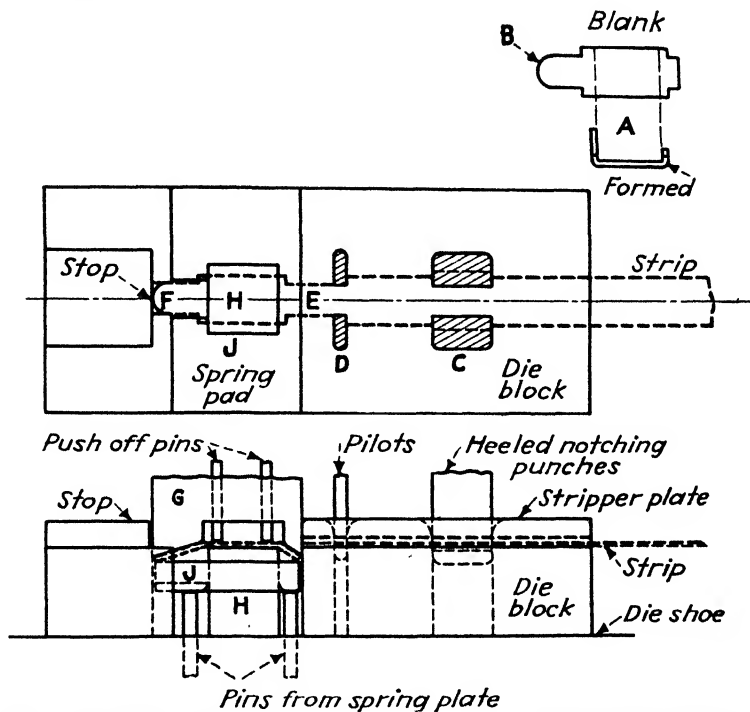
FIG. 324.—Progressive die for producing piece A. The ends are trimmed and cut off by punch G just before forming.

The method illustrated notches the strip at C, aligns it with pilots at D, and cuts square across the neck at E. The round end is trimmed at F by the descent of forming punch G. The forming punch, continuing in descent, forms down the ends of the piece over block H while spring pad J descends. In the punch ascent, the work is ejected by the pad and two push-off pins through the punch. The work is then blown from the die by compressed air.

Double-action Die for Hollow-nut Blanks.—The nut is shown at A, in Fig. 325. The threading is, of course, produced in another operation. Both the inner and the outer slides are at the bottoms of their strokes.

The brass strip *B* is fed from right to left across the face of die block *C*. The die is positively attached to die shoe *D*, and blanking punch *F* is similarly attached to punch holder *H*. The punch holder is attached to the face of the blank-holder ram, which is the outer sliding member. The inner sliding member operates the drawing punch *I*, which is attached to it.

At the first station, a center hole is pierced in the strip, which is then advanced into the second station. The hole is drawn up over pin *L*, of suitable size for subsequent tapping. The blanking tools
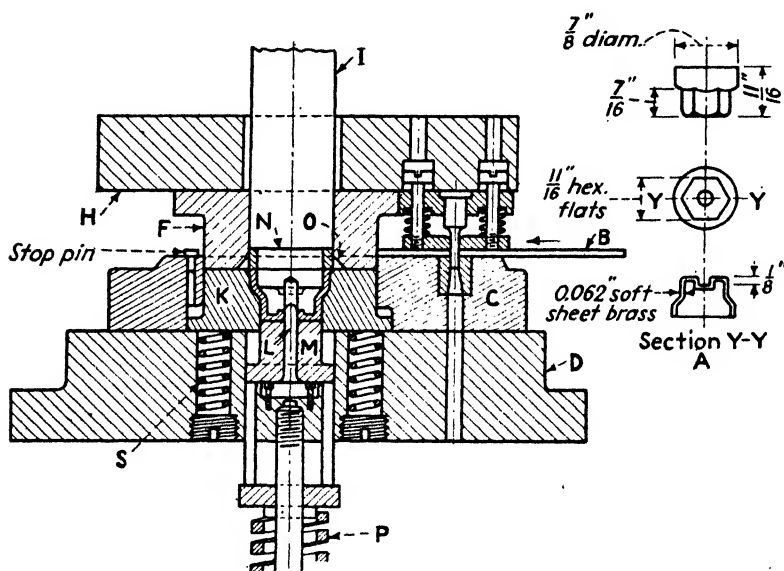
Fig. 325.—The hollow hexagonal nut at *A* is produced from sheet brass in a double-action press using this two-station piercing, blanking, and drawing die.

cut a round blank from the strip, and the blank is carried down between the faces of blanking punch *F* and spring pad *K*. Shedder *M* "banks" in the die shoe around pin *L*, thus spanking the work that has been drawn down into the die. This action shapes the work and tends to produce sharp hexagonal corners.

On the upstroke of the press, the finished work is ejected by shedder *M*, by means of the strong compression spring *P*. Simultaneously, springs *S* return pad *K* flush with the surface of the die block. The finished piece is stripped from the drawing punch when it ascends through the blanking punch. Cutting ring *N* "pinch trims" the top of the nut. Space *O* takes care of the trimming scrap until the nut is ejected and blown off the die by compressed air.

Single-action Die for Hollow-nut Blanks.—The nut at A in Fig. 325 is produced in a single-action press as follows. In Fig. 326 a center hole is pierced in the strip at a first station. At the second station a round blank is punched from the strip. The work is located by pilot A which enters the hole just pierced. When the ram ascends, the blank is pushed back into the strip by action of the rubber bumper B. Spring pad H holds the strip down on the die for returning the blank. The strip is then fed forward.
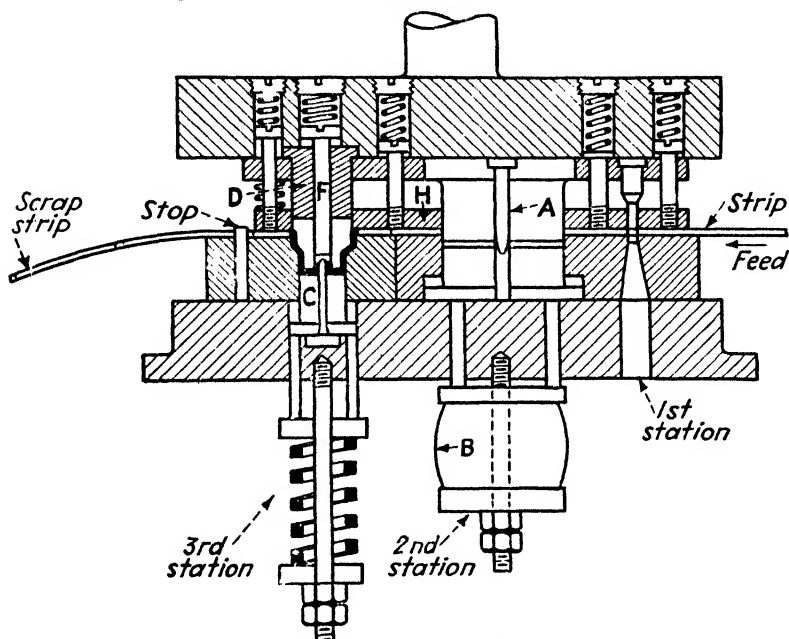
Fig. 326.—Three-station combination die for producing the nut shown at A in Fig. 325, in a single-action press.

At the third station the blank is drawn, the center hole is embossed inwardly to the correct size, and the irregular top of the nut is pinch trimmed by a cutting ring. As the ram ascends, the spring-actuated shedder C follows up with the work and ejects it from the die. The work is stripped from the punch by contacting stripper H. The work is blown from the tools by an air jet.

Cut-and-carry Die for Hollow-nut Blanks.—The nut at A in Fig. 325 is produced in a cut-and-carry die as follows. In Fig. 327 a center hole is pierced in the strip at a first station. Two sides of a round blank are cut in die opening B, while a pilot punch registers the strip in the previously pierced hole. The blank is attached within the scrap frame, as shown.

In the third station a cup is drawn up into a die above the strip by a punch through spring pad *C*. The dies above the strip are all attached on the face of the punch holder and are provided with spring shedders. The fourth station redraws the cup, embosses the center hole, and forms the hexagonal sides of the nut. In the fifth station the piece is sized, pinch trimmed, and cut from the strip. When the ram ascends, the work is ejected from the dies by spring shedders.

However, in dies of these types, it is best to introduce more redrawing stations than shown in the engraving. Single-station experimental dies are usually made to determine the number of cut-and-carry stations needed. Scrap-cutting blades, to the left of the dies, are
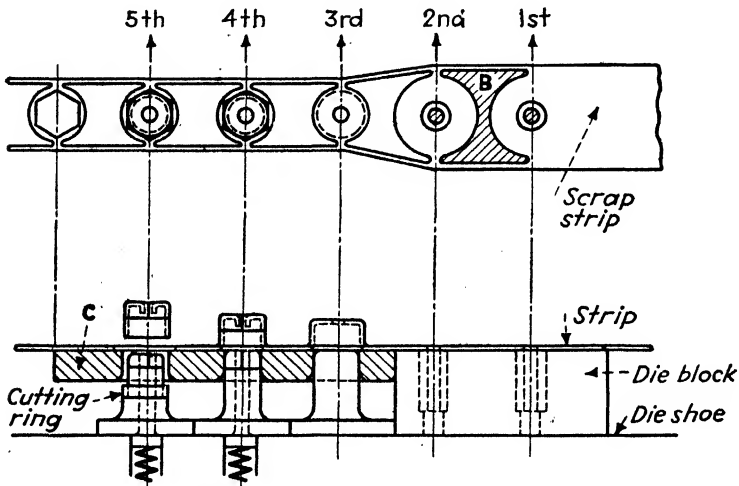
FIG. 327.—Blanking and drawing shells in cut-and-carry dies.

sometimes installed to sever the scrap frame into blanking-center lengths. All the drawing operations are protruded above the strip. For this reason, the strip and operations can be easily advanced from station to station.

Forging Propeller Blades.—A typical hot-forging job is illustrated by the reproduced photograph in Fig. 328. This operation is produced in a large straight-side forging press.

Forging dies are usually worked out with half the desired form in one die block and half in another. "Edge draft" is provided in the peripheries of both dies for ease in removing the forged piece by hand The operator in the picture is removing one of the blades.

The rough cutting and shaping of the interiors of forging dies is either done in a die-sinking machine or traced from a wooden template

in a Keller horizontal end-milling machine. The rough cuts are subsequently ground smooth by hand. The degree of finish depends upon the requirements of the work. At two of the diagonally opposite corners of the blocks are rectangular bosses and corresponding recesses. These are used for aligning the dies in the press.

The material used in this operation is of the 11S type of aluminum alloy. The heat-treated temper of this particular aluminum for

Fig. 328.—Forging aluminum propeller blades in a straight-side press. (*Courtesy Aluminum Company of America.*)

forging is designated 11S-T. The slight "flash," or "fin," around the edges of the piece is to be trimmed off later. Easy machining is one of the desirable features found in this grade of aluminum alloy.

Stretching an Elbow with Steel Balls.—Figure 329 represents a stretching and drawing die at two of its cycles while producing from shell *A* the brass elbow drain pipe shown at *B*. This is one case in which a mechanical die operation can be advantageously substituted for a hydrostatic die.

Shell *A* is previously prepared in three ordinary drawing operations; it is then annealed, the flange trimmed, and six mounting holes pierced. The shell is placed in die *C* and loaded with two steel balls. Sizes of the balls correspond to the inside diameter of the shells. When the punch descends, pins in the blank holder engage in the holes around the flange. The flange is firmly held down on the die by the blank holder. The punch, continuing to descend, forces the balls to draw
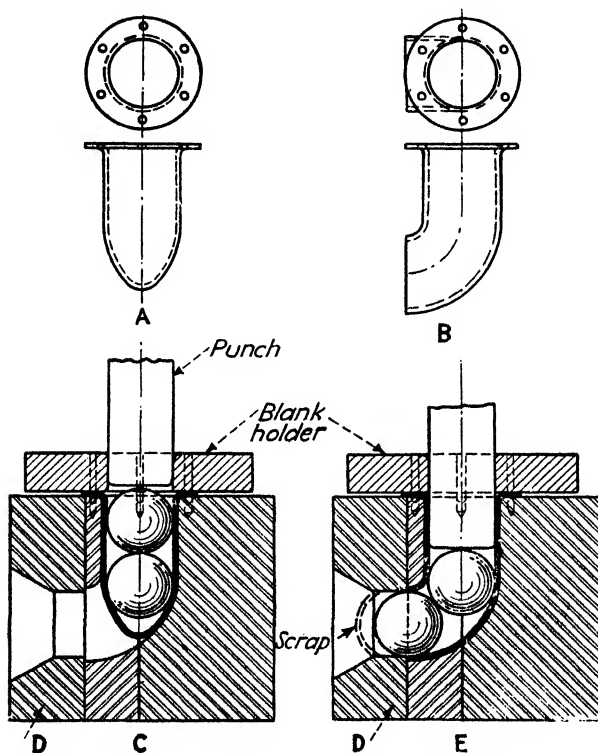
Fig. 329.—Die using steel balls for drawing and stretching a right-angled pipe elbow from an annealed brass shell.

the elbow and to stretch it to size. At the entrance of plate *D*, the end of the elbow is pinched off. The diameter of this entrance corresponds to that of the balls. The trimmed scrap is forced out with the first ball, as seen in sketch *E*.

The die is composed of two parts. It has a vertical split along the center line of the punch. The right-hand section can be moved away in a slide. It can be firmly locked with a cam in a shut position, as in a split hydrostatic die. After the punch and blank holder have

ascended, the finished work is removed by opening the die slide. The second ball is dumped out at the flanged end of the elbow.

This operation, taken from practice, indicates the feasibility of performing other similar operations with steel balls. Such operations might be raising a flange from the side of a pipe, stretching out the head of a tee instead of an elbow, or embossing a bulge in the sides of shells.

Centralizing Material Strips over Die Openings.—The upper and lower wedges *A* and *B*, in Fig. 330, are required to move equally and horizontally by a crosswise movement of bar *C*. For doing this, angles and rollers are used which are actuated by the rack-and-pinion movement shown in connection with hand lever *D*. The wedges
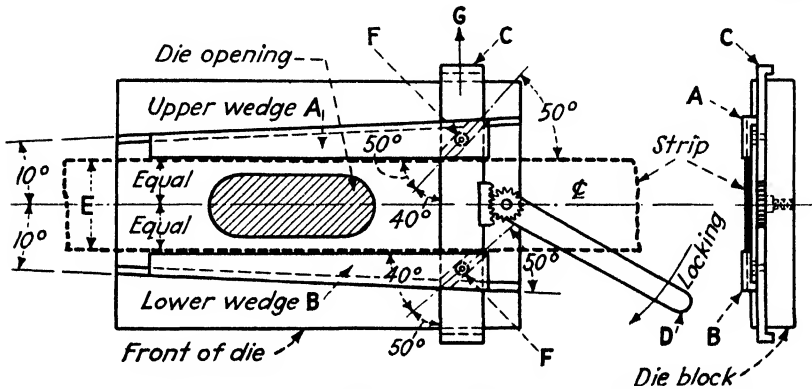
Fig. 330.—Attachment for centralizing a material strip over the die opening.

move—or slide, rather—in 10-deg. angular slots, equally positioned on both sides of the die opening.

The object is to clamp and centralize material strips of slightly variable widths *E*, between the parallel sides of the two wedges. Follower rolls *F* are fixed to revolve on the crossbar and ride in angular driving slots which are cut across the ends of the wedges. The problem is to determine the correct angles for the driving slots, so that both wedges will have equal forward movements.

This is an example in relative motions. Such motions are usually hard to understand clearly. Since the wedges are of opposite hands, that is, right and left, the driving angles relative to bar *C* must not be equal. If they are made equal, it has been found that when bar *C* travels in the direction *G*, the upper wedge moves ahead faster than the lower in closing. This fault, of course, defeats the purpose of accurate centralization. If both wedges are straight, that is, if the 10-deg. angles are zero, then the correct driving angles will obviously

be equal. In that case, 45-deg. angles would, of course, be selected for easy driving. The total differential is 10 deg., in which 5 deg. is involved in each wedge. Therefore the upper angle is made (45 *less* 5 deg.) relative to the bar, and the lower (45 *plus* 5 deg.), or 40 and 50 deg., respectively.

Other mechanisms can be used for moving the wedges that would eliminate the problem of relative motions. A shaft across the right end of the die, with eccentrically operated links attached at the ends of the wedges, is one of them. The illustration given was taken from practice. It indicates how easily a simple tool design may go astray, if all the details are not clearly understood.

Bending and Forming Blanks between Rollers.—If various cross-sectional shapes of sheet-metal moldings can be produced in roll-
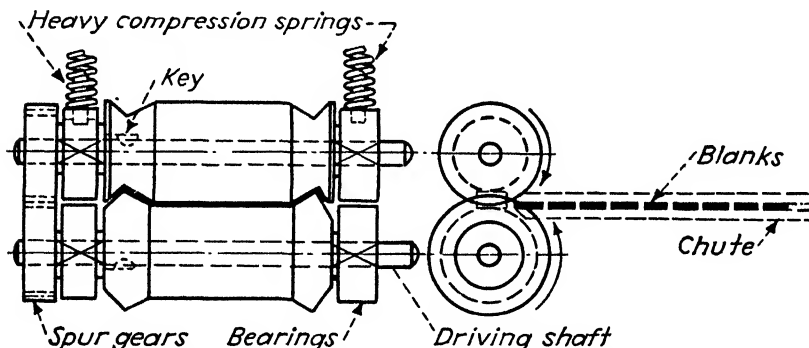
FIG. 331.—Set of rollers for bending and forming long narrow blanks. This operation is much faster than bending the same blanks in ordinary forming dies.

forming machines, then blanks of even widths can also be similarly formed. This operation, although new in some shops, has been done on a production basis for a number of years.

The principle is very simple and is illustrated in Fig. 331. It is best to use average diameters for the rolls, in order to obtain equal surface speeds for each roll. The sum of the larger and smaller diameters is divided by the number of diameters used, to obtain the average. The least diameter should be about fifteen or twenty times the blank thickness.

One roll drives the other through a pair of spur gears. The upper roll bearings are designed to "float vertically" under strong compression springs. This feature compensates for variations in material thicknesses. The work pieces are fed between the rolls through either a horizontal chute or one placed at an angle. Blanks of different widths in the same piece can be formed if two separated edges enter

the rolls together. Blank lengths must pass through parallel with the rolls; otherwise the bends will not be straight. This method of forming is many times faster for bending certain parts than placing them one by one in an ordinary bending die. Safety guards should be placed over the gears and in front of the upper roll.

A Collapsible Punch That Centralizes.—Long bends in certain formed work are sometimes difficult to strip from the punch after the
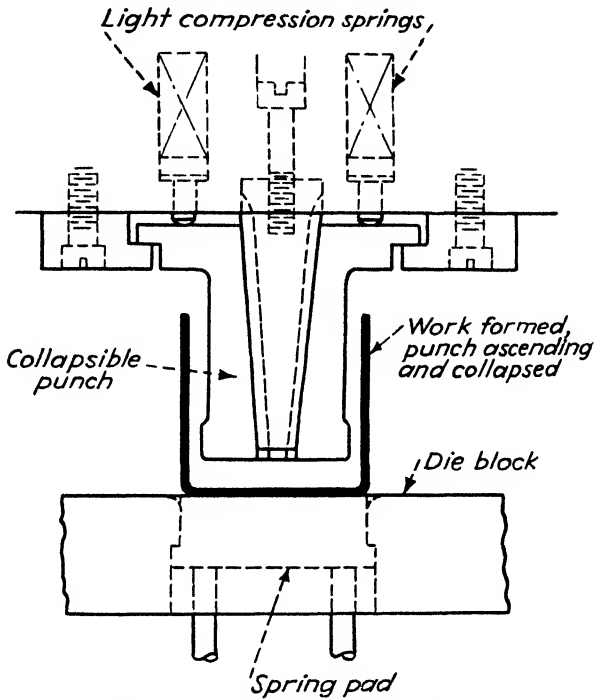
FIG. 332.—A centralizing collapsible forming punch that leaves the finished work standing on the die when the ram ascends.

operation. There may not be enough space, when the ram is down, for "skyhooks" or other means of stripping unless deep clearance holes are cut into the punch holder, and this is usually objectionable.

Figure 332 depicts a punch design that automatically centralizes itself in descent and ascent. It frees the work immediately after forming, when the punch, in ascent, begins to collapse the instant that it leaves the die. Springs under the pad are very much stronger than those behind the punch.

Combination Perforating, Blanking, and Drawing Die.—The drawn cup in Fig. 333 is produced in the combination die illustrated

in Fig. 334. The tool drawing represents the design, the method of operation, and the usual drafting technique for viewing the dies of this type. All the tool parts are round and therefore rough turned in a lathe. This tool design represents a large variety of sizes for combination dies. If the work in Fig. 333 were ten or fifteen times the given sizes, the general tool design would be the same. In larger dies, however, it would be more economical to use tool-steel-faced punches and dies backed up with cold-rolled or machinery steel.
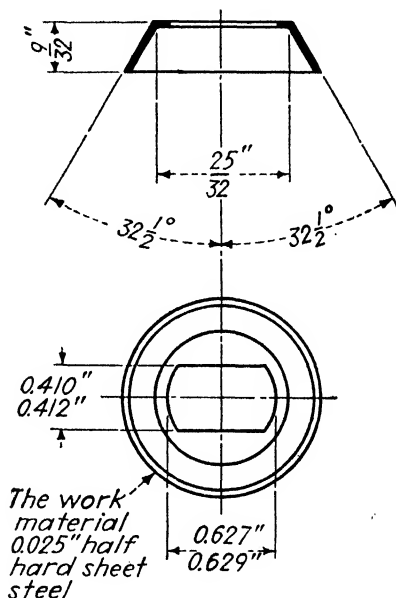
Fig. 333.—Cup with a large perforated opening cut through its bottom. This item is perforated, blanked, and drawn to size in a single-station operation.

In Fig. 334 the names of tool parts are as follows: *A*, spring-pressure pad; *B*, perforating punch; *C*, backup plate; *D*, upper shedder; *E*, blanking punch and drawing die; *F*, drawing punch and perforating die; *G*, lower shedder; *H*, spring-plate ejector, of which two are required; the second plate, not shown, is used at the bottom ends of spring posts *I*; *J*, spring pad that holds the strip down on the die when blanking; *K*, die block. *L* is a threaded retaining plug, and *M* the stop pin for halting the strip between blanks. The perforated slugs fall out through *F*, then through an enlarged opening in the die shoe and through a larger opening in *H*.

Double-action Blanking and Drawing Operations.—Figure 335 depicts the ordinary drafting technique, tool design, and indicated

operations in producing a first-operation rectangular aluminum pan (Figs. 336 and 337). The die is shown closed. The sides of the pan are given a slight taper in the die, as shown. This feature tends to avoid scratches on the work and promotes easy ejection.
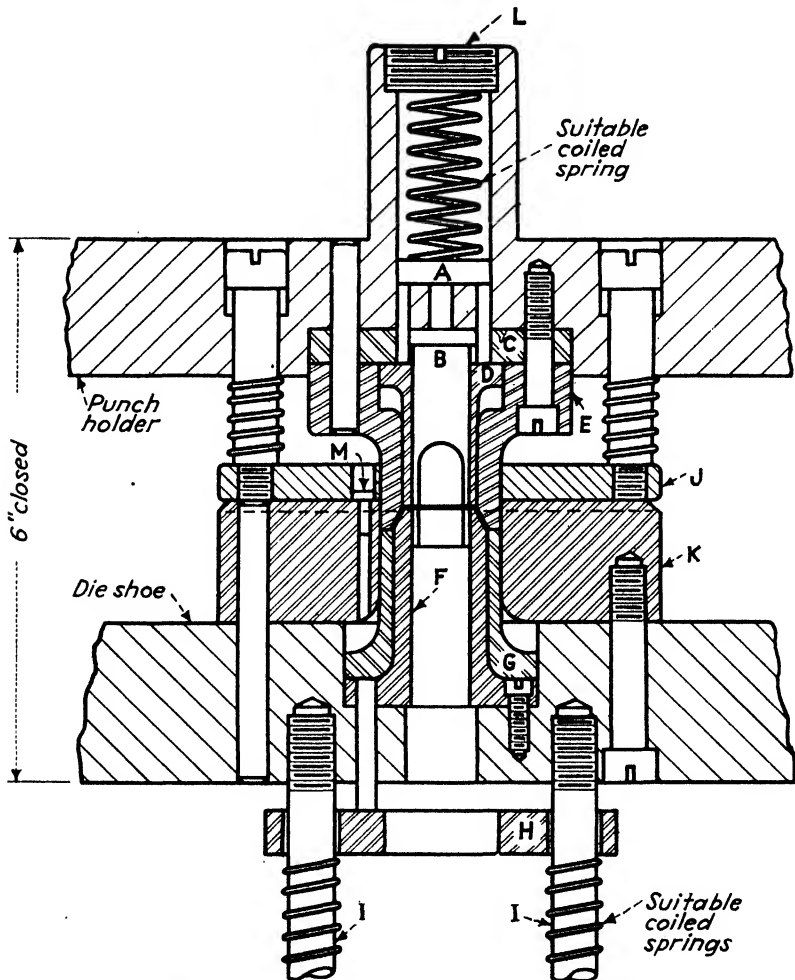
Fig. 334.—A representative type of combination die. This tool blanks, perforates, and draws a flared cup at one station.

In some drawing dies, cast-iron punches and drawing dies can be used, if a few scratches on the work are permissible. There are several grades of alloyed cast irons in the market that can be finished smoother than ordinary cast iron. Using cast iron or its alloys in place of tool

steels is economical in large dies. Cast-iron drawing members are commonly used in dies for automotive or farm machine parts and similar operations. These parts are finished to templates, when necessary, using hand grinders. Cheap tool steels, known as "8-ct. tool steel" and "Macolloy No. 2" grades, are also available. Carburizing machinery steels for draw tools is being investigated. The tests have
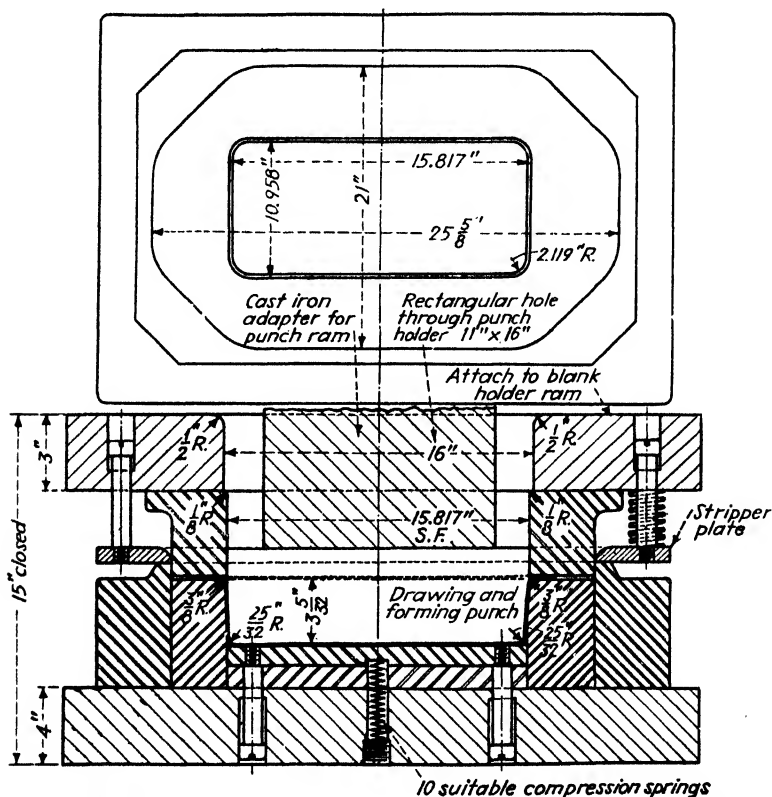
Fig. 335.—First operation, double-action blanking and drawing die for the aluminum pans shown in Figs. 336 and 337.

not gone far enough to warrant definite conclusions. The indications are that they may be satisfactory for certain applications where high-priced tool steels were formerly used.

Designing Draw Dies for Aluminum.*—The correct design of drawing tools is a very important factor in obtaining satisfactory shells. The general principles of design are the same as for other

* J. T. Weinzierl, tool engineer, The Aluminum Cooking Utensil Co., New Kensington, Pa. (Courtesy Aluminum Company of America.)

Fig. 336.—This aluminum pan was drawn in three operations. The flow of metal is shown by the change in position of concentric circles and radial lines. The amount of distortion in various parts of this rectangular pan is readily apparent. (*Courtesy Aluminum Company of America.*)
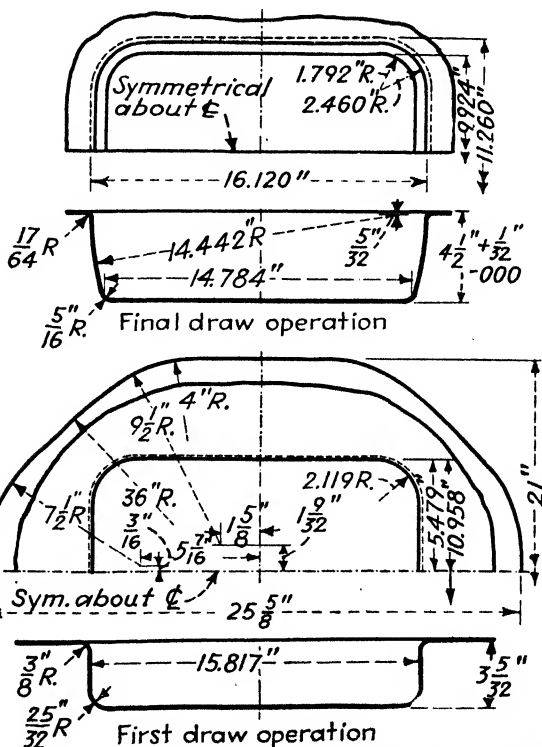
Fig. 337.—Typical first and last operation shells and the developed blank for a rectangular aluminum pan. (*Courtesy Aluminum Company of America.*)

metals, but the amount of reduction per draw, the radii on the tools, and the change in metal thickness will vary.

Reduction per Draw.—The reductions in diameter per draw for safe commercial production of 2S-O and 3S-O for deep-drawn cylindrical shells are as follows:

Operation	Symbol	Desired reduction, per cent	Permissible reduction, per cent
Blank....................................	D		
First draw..............................	(D_1)	40 (or less) D	42 D
Second draw............................	(D_2)	20 D_1	25 D_1
Third draw.............................	(D_3)	15 D_2	18 D_2
Fourth draw............................	(D_4)	15 D_3	15 D_3

These reductions may be varied to some extent; but for sheet of commercial tolerance, trouble is usually encountered from fracturing of the metal if they are exceeded.

For harder tempers of these alloys and for harder alloys such as 52S and 4S the reductions per draw have to be reduced. The increased hardness increases the resistance to flow of the metal to such an extent that fractures may occur when using the high reductions that are satisfactory for the annealed 2S and 3S sheet. In many cases, this decrease from the desired reductions given in the table may amount to 10 per cent on the first draw and 5 per cent on succeeding draws depending on the hardness of the metal being fabricated.

Radii on Draw Tools.—The radius on the die should be approximately a minimum of 4T and a maximum of 15T, where T is the thickness of the original metal, that on the punch being held to a minimum of 4T. The sharper the die radius the greater the resistance to the flow of metal. This resistance to metal flow is one cause of fracture during the drawing operations. On the other hand, if the radii are too large, a great portion of the metal in the blank is not under control while being drawn, and this may cause the formation of wrinkles. A liberal radius on the vertical corners of rectangular shells is advisable, as otherwise there will be too great a resistance to the flow of metal in this area.

Change in Thickness of Metal.—The draw tools for aluminum should be designed so as to produce the minimum possible change in the thickness of the original blank. In many alloys, such as brass and steel, the reduction in cross section of the blank may be as high as 50 per cent of the original thickness. Such a forming procedure is

usually not applicable to aluminum alloys. For this reason it is often necessary to redesign tools used for drawing other metals and alloys when it is desired to produce a similar shape from aluminum.

Rectangular Shapes.—The flow of metal in drawing a rectangular shape is illustrated by the change in dimension of the original squares as illustrated in Fig. 273 and the change in radial lines and concentric circles as illustrated in Fig. 336. These photographs show that the greatest movement of metal occurs at the corners. The die and blank holder must therefore be constructed to control this flow of metal so as to avoid both wrinkling and fracture.

This can be done by making the draw radius at the corners slightly longer than at the sides and ends, taking care to have the radii of different lengths blend smoothly into each other. Increasing the draw radius at the corners helps to reduce the resistance to flow caused by thickening of the metal. A procedure commonly used is to hollow out the face of the blank holder to provide the necessary clearance between the die face and blank holder to allow for this increase in thickness. This clearance should correspond nearly to the increase in thickness, because if it is too great, buckles extending radially from the corners will form in the drawing operation.

The dimensions of the original blank must be developed to obtain the proper amount of metal that is necessary to obtain the desired shell. The shape of the blank will vary greatly with the proportions of the rectangle and depth of shell to be drawn. A shallow rectangular pan or tray will require a blank of rectangular shape with the corners rounded. The blanks for a rectangular shell of medium depth will have only short, straight sides and ends with the corners cut away on a double ogee curve. Deep rectangular shells may be drawn from circular or elliptical blanks depending on the width-to-length proportion of the shell. Care should be exercised to use as little metal as possible in the blank, as the excess metal increases the drawing difficulties. Typical first- and final-operation shells, as well as the developed blank for a rectangular pan, are illustrated in Fig. 337.

Cylindrical Shape.—The flow of metal in drawing cylindrical shapes is shown by the change in dimensions of squares as illustrated in Fig. 338 for the first draw, Fig. 339 for the second draw, and Fig. 340 for the third draw. A careful check shows that even though the dimensions of the original square have been changed considerably, the area remains practically the same, indicating little change in thickness of the metal during the drawing operation.

The sequence of drawing operations and the diameter of the original circular blank are given in Fig. 341. Since the metal moves
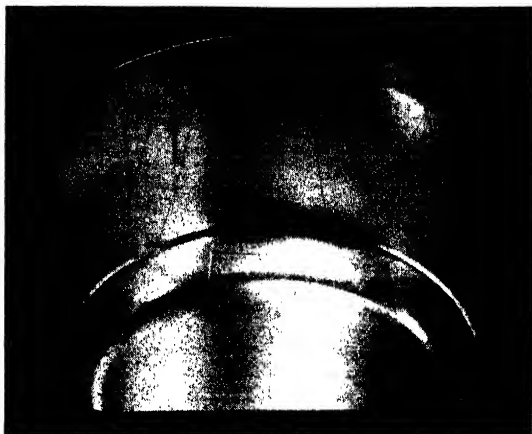
FIG. 338.- -Showing the flow of metal in the first drawing of a cylindrical shell. The change in the size of the squares can be readily seen.
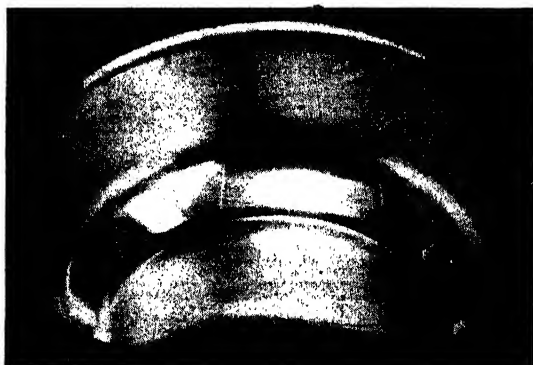
FIG. 339.—-This is the second draw on the shell shown in Fig. 338. A further change in the size of the squares is apparent.

FIG. 340.—This is the third operation on the shells shown in Figs. 338 and 339. Notice that the metal above the bottom of the shell has been distorted considerably.

the same in all parts of a symmetrical shape, no allowance has to be made in any particular part of the tool for thickening of the metal, as was the case in rectangular shells.

Dome, Bowl, and Hemispherical Shapes.—The flow of metal in dome, bowl, or hemispherical shapes is similar to that in cylindrical shapes. The dome or hemisphere is often difficult to obtain in draw-
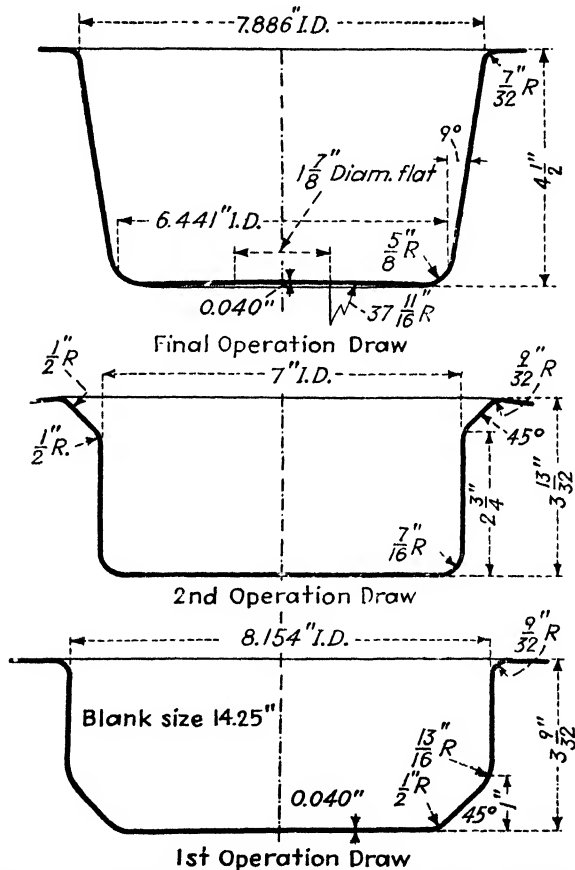
Fig. 341.—Sequence of drawing operations and diameter of the original circular blank.

ing, especially with thin-gage metal, because of the tendency to form wrinkles. In order to avoid difficulties in drawing such shapes, a preliminary draw is often required to obtain a sufficient amount of metal in the correct position before the final forming operation. If there is an excess of metal, wrinkling of the shell will occur, whereas insufficient metal will cause fractures.

The procedure for drawing a bowl-shaped shell is illustrated in Fig. 342. The dimensions of the radii in the first drawing operation are very important. The shell must have sufficient metal at the proper positions so that the second draw can be performed without difficulties.

Odd Shapes.—Besides the shapes that have been discussed, various odd shapes are often desired. The flow of metal in such shapes may be a combination of those discussed. The sequence of operations for drawing a triplicate saucepan, as well as the original blank, is illustrated in Fig. 343. Special attention should be given to the shape of the
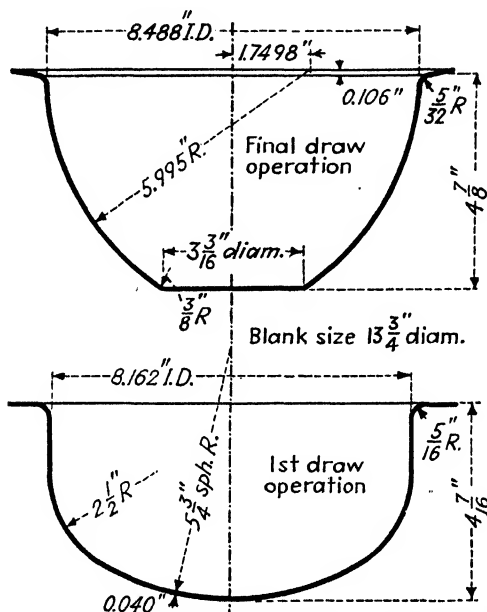
Fig. 342.—Procedure for drawing bowl-shaped shells.

blank so that the least amount of metal will be used to obtain the desired shape.

Dies with Elevated Stripper Plates.—This method of stripping, after blanking, is similar to the "sky-hook" principle used for stripping formed work. In the consecutive production of blanks from a strip, when using a semicompound die, a serious difficulty arises. The ejected blanks from the die will interfere with rapid production.

Figure 344 represents the design for a semicompound die that avoids this trouble. The die block with its shedder is secured on the die shoe in the conventional manner. An elevated stripper plate is positively attached to the die. After the blank is cut, the punch ascends and

carries up the strip into contact with the stripper plate. The cut blank remains on the die; but while the strip is elevated, the blank is blown behind the press by compressed air. This method of handling the strip provides the means for rapidly cutting successive blanks in regular order.
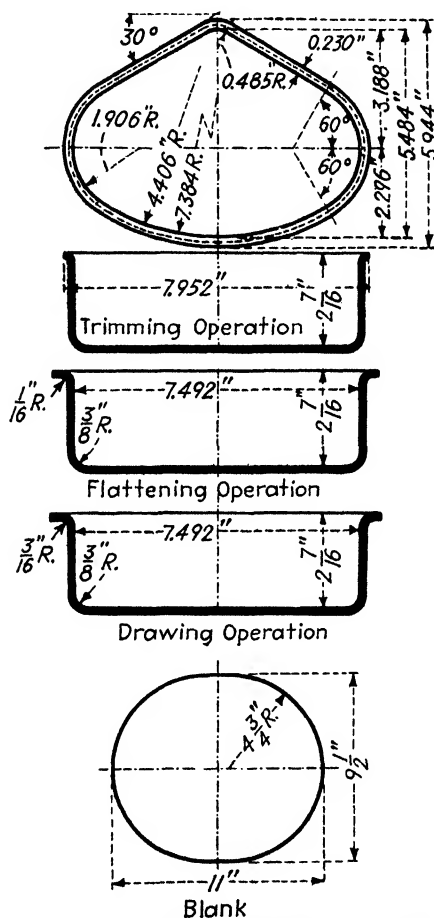
FIG. 343.—Sequence of operations for drawing triplicate sauce pans.

If it is necessary to hold the strip down on the die while blanking, the plate can be operated by light compression springs. The plate is made to slide on a spring post at each of its corners. Stripping is done with the punch in ascent, when the plate contacts positive hooks, or stops. The blank is blown from the die, before stripping occurs, as described above.

Curling and Wiring.—Curling operations are very simple, but troublesome if certain important principles are overlooked. The radius of the curl should not be less than about twice the blank thickness. This depends, of course, on the nature of the job and the ductility* of the work material.

Ordinary methods of curling include two different die designs. For curling hinges (Fig. 345) the operation is usually performed in a die block secured on the die shoe. For other curling operations, such as wiring at *A* in Fig. 346, the curling die is ordinarily attached on the punch holder. However, these conditions may be reversed to suit individual jobs. The curling radius in the die should be smoothly
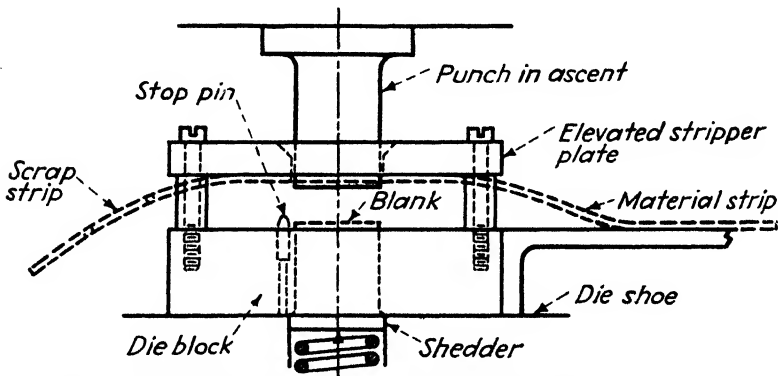
Fig. 344.—A semicompound die in which the blank is left lying on the die shedder when the punch ascends. The strip is carried up with the punch and into contact with an elevated stripper plate. Space between the die and stripper plate permits the blank to be blown off by compressed air before the strip descends.

polished. The inside surface of the blank must be held positively in line with the inside curling radius of the punch. The outside surface of the blank must be in line with the radius in the die. The burr edge of the work should be the inside edge of the curl, with the rounded edge on the outside; otherwise the burr edge will wear the die radius rapidly (Fig. 345).

In the manufacture of cheap hinges, the blanks are pierced and notched from strips that enter the dies from the right and left sides of the press. The widths of the strips are equal to the length of the hinge. The two parts of the hinge meet and are then curled around

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* It may be useful here to explain the meanings of ductile and malleable. These terms are often confused in reference to the drawing and rolling qualities of metals. "Ductility" refers to the drawing qualities of a metal without showing fractures. "Malleability" refers to those qualities in metals which can withstand hammering or rolling without showing fractures.

the hinge pin; the leaves are cut off; and the hinge is completely fabricated and assembled in one press operation.

In wiring operations the stresses of metal are both compression and tension, but they seldom cause cracks or ruptures, unless the work
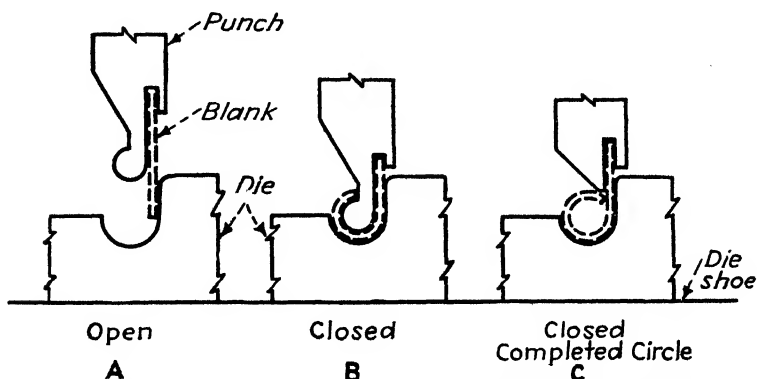
FIG. 345.—At *A* the blank to be curled is positioned before the punch descends. At *B* the curling operation is shown completed. At *C* a different punch design is shown that curls a completed circle.

diameter is comparatively small. The diameter of the work should not be less than about twenty-five or thirty times the material thickness, or six to seven times the outside diameter of the curl.
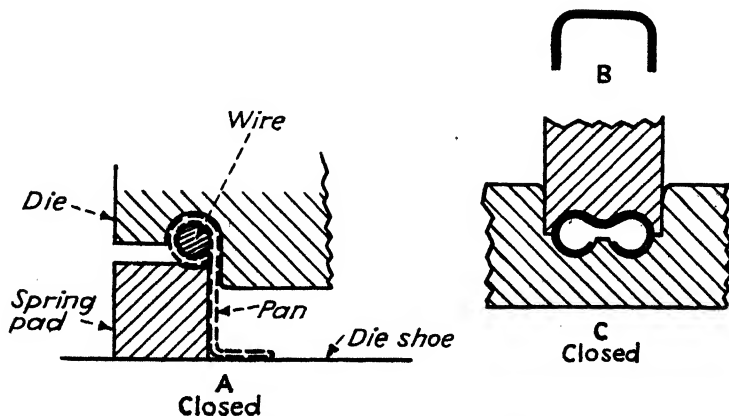
FIG. 346.—At *A* is a section through a wired curled edge of a pan. At *B* is another first operation, or the start for two curls in a straight piece of work. At *C* the second operation on *B* has been completed, and the curls are shown in the closed die.

Wiring the edges of a cup or pan stiffens the circumference. There are two varieties of wiring: *false* and *real*. In the first named, the edge is simply curled within itself without enclosing a wire. Most

kitchenware has curled edges of this type. In the other variety, a circle of wire is placed on a spring pad that surrounds the pan. When the curling die descends, the edge of the pan is forced to curl around the wire, as shown at A in Fig. 346. The pan must have an internal supporting rim around the die which enters the pan before curling, as shown. The rim prevents the pan wall from collapsing.

Wiring operations are most frequently done on a "horning-and-wiring" press. In this type of machine the shut height is adjustable to greater lengths than in ordinary presses. This feature permits the
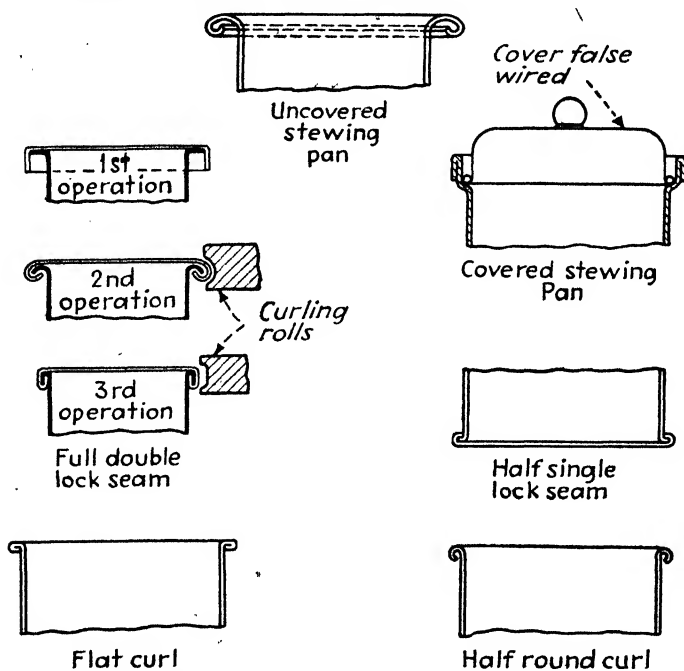
FIG. 347.—Typical lock seams and curled edges used in culinary ware.

wiring of deep pans and cans with a comparatively short press stroke. Wiring jobs on small shallow pans can be done in plain gap presses.

Several other methods are, of course, employed for trimming and wiring in which the punch press is entirely eliminated. The interior of a pan may be placed over a close-fitting nose, or chuck, mounted on a headstock as in a spinning lathe. A pressure plate is then brought into contact with the bottom of the pan. The plate and pan revolve together. While the pan revolves, a tool head comprising two cutting rollers is advanced and trims off the irregular edge of the drawn pan. Another tool head, carrying the wiring rollers, is then

advanced and curls over the edge. This operation is performed for either false or real wiring.

Similar trimming and wiring jobs are done in vertical machines which are commercially built for that purpose. The method is similar
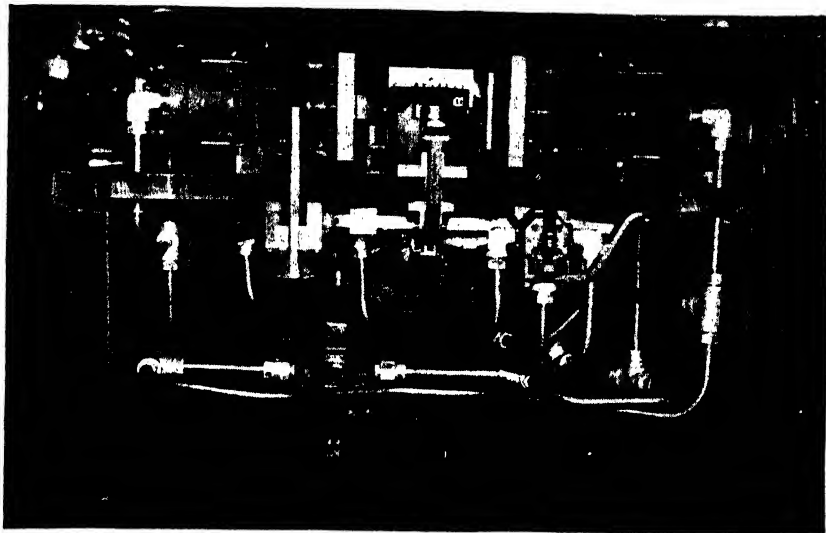
Fig. 348.—Hydropiercing machine.

in principle to those of rotary swaging machines. Rollers or burnishing tools start the curl and close it when the initial curl passes between other suitably shaped rolls. These machines are also designed to perform lock-seaming operations, in which either the top or the bottom of a cylindrical receptacle is assembled on a can.

Fig. 349.—Streamlined frame pierced and notched in a hydropiercing machine.

Locked Seams and Curled Edges.—Several of these types are shown in Fig. 347, and some of the methods employed in producing them. Most of the samples were taken from aluminum ware.

Hydropiercing Methods.—Figure 348 is taken from a photograph of a recent type of hydropiercing machine. It shows three horizontal

hydraulic cylinders for operating piercing dies for cutting round holes and other shapes. One of the spring stripping plates is seen in front of the cylinder at the right. This machine is designed to pierce, shear, form, and emboss the streamlined channel frame shown in Fig. 349. The pistons are advanced by hydraulic pressure, but quick reverses are made by introducing compressed air on the piston heads opposite the hydraulic sides. The hydraulic and pneumatic valve controls are the two levers shown in the foreground.

These machines have an advantage in the ease by which other cylinder units and new operations can be substituted or added. They are becoming increasingly popular for operations that involve odd shapes in automotive work and streamlined train parts. In airplane fabrication, where the designs of parts are constantly changing, this flexible type of light presswork has been very well received. The variety of stamping and pressing operations for which these machines can be arranged is limited only by the ingenuity of the designer. A motor-driven hydraulic pump and sump tank are necessary for operating, but compressed air can be taken from the shop air line.

CHAPTER XXIII

MATHEMATICS FOR PRESS TOOLS AND PRESSES

The Ability to Handle Common Mathematical Formulas Is an Important Part of a Tool Engineer's Training

Natural Trigonometric Functions.—If the length of hypotenuse c in any right-angled triangle (Fig. 350) is unity, or 1, and if the length of any side is divided by the length of any one of the other sides, the resulting quotient is called a "natural trigonometric function." By this simple computation, all the given decimal numbers for sines, cosines, tangents, and all the other trigonometric functions of angles have been found and tabulated. The following formulas cover practically all the right-angled triangle problems that arise in daily practice.
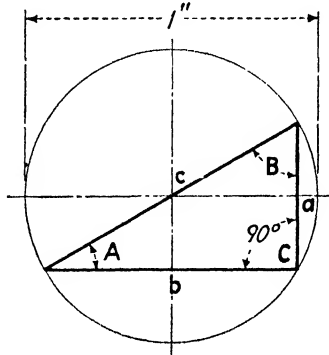
FIG. 350.—Illustrating the derivation of the natural trigonometric functions for right-angled triangles.

$$\sin A = \frac{a}{c}, \qquad a = \sin A \times c, \qquad c = \frac{a}{\sin A}.$$

$$\cos A = \frac{b}{c}, \qquad b = \cos A \times c, \qquad c = \frac{b}{\cos A}.$$

$$\tan A = \frac{a}{b}, \qquad a = \tan A \times b, \qquad b = \frac{a}{\tan A}.$$

$$\cotan A = \frac{b}{a}, \qquad b = \cotan A \times a, \qquad a = \frac{b}{\cotan A}.$$

$$\sec A = \frac{c}{b}, \qquad c = \sec A \times b, \qquad b = \frac{c}{\sec A}.$$

$$\cosec A = \frac{c}{a}, \qquad c = \cosec A \times a, \qquad a = \frac{c}{\cosec A}.$$

Pythagorean Theorem.—This is a high-sounding term, but it simply means that in any right-angled triangle (Fig. 350) $c^2 = a^2 + b^2$. By transposing terms we find that $a^2 = c^2 - b^2$ and $b^2 = c^2 - a^2$. These three formulas are often used in tool and machine engineering.

Law of Sines, Cosines, and Tangents.—From these laws, several useful formulas have been derived. The following equations refer to Fig. 351.
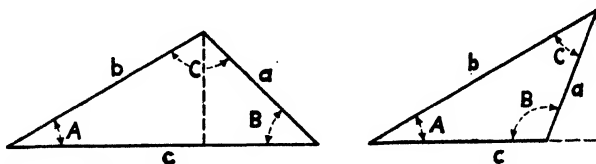
Fig. 351.—Obtuse-angled triangles, either of which illustrates the formulas covering the law of sines, cosines, and tangents.

Law of sines:

$$\frac{a}{b} = \frac{\sin A}{\sin B}, \qquad \frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}.$$

Law of cosines:

$$a^2 = b^2 + c^2 - 2bc \cos A.*$$

Law of tangents:

$$\frac{a - b}{a + b} = \frac{\tan \frac{1}{2}(A - B)}{\tan \frac{1}{2}(A + B)} \text{ when } a \text{ is greater than } b.$$

$$\frac{b - a}{b + a} = \frac{\tan \frac{1}{2}(B - A)}{\tan \frac{1}{2}(B + A)} \text{ when } a \text{ is less than } b.$$

Finding the Angles in Any Triangle, Given Three Sides.—The law of cosines is used for determining the angles in any triangle (Fig. 352) in which the three sides are known. There are two formulas for this problem.
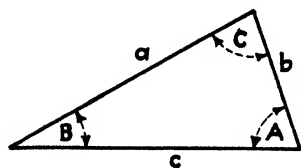
Fig. 352.—Given three sides of any triangle, to find the angles.

$$\cos C = \frac{a^2 + b^2 - c^2}{2ab},$$

or

$$\cos C = \frac{(a + b + c)(a + b - c)}{2ab} - 1.$$

For solving angles A and B,

$$\sin A = \frac{a \sin C}{c}, \qquad \text{and} \qquad B = \dagger 180° - (A + C).$$

* When letters and figures are written side by side, with no sign between, it indicates multiplication of the quantities; thus: $2bc \cos A$ means $2 \times b \times c \times \cos A$.

† The sum of the angles in any triangle is 2 right angles, or 180 deg.

In solving the angles for triangles, given the three sides, it is sometimes necessary to turn the triangle on to a base so that $a^2 + b^2$ will exceed c^2. This is usually necessary for triangles in which two of the sides are each several times the length of the third side. This change, if necessary, can easily be taken care of by inspection before computations begin.

Solving the Vertical and Horizontal Dimensions for Triangles.— In Fig. 353, dimensions A, B, and C are given, and H, X, and Y are required.

$$X = \frac{A^2 + C^2 - B^2}{2C}. \qquad Y = C - X, \qquad \text{and} \qquad H = \sqrt{A^2 - X^2}.$$
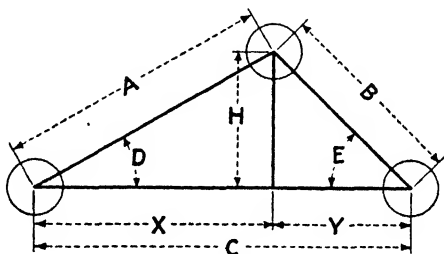
Fig. 353.—Illustrating the formulas for solving the vertical height H, and the horizontal dimensions X and Y, given A, B, and C.

Another solution for H is to find angles D and E, as given by formulas in the preceding figure; then

$$H = \frac{C}{\text{cotan } D + \text{cotan } E}.$$

This formula is a very important one in shop trigonometry. It will often be referred to in the pages ahead.

Relation between Sine, Cosine, and Tangent.— Referring to Fig. 350, we have the following proportions:

$$\tan A = \frac{\sin A}{\cos A}, \qquad \text{hence} \qquad \sin A = \tan A \times \cos A, \qquad \text{and}$$

$$\cos A = \frac{\sin A}{\tan A}.$$

The versed sin of angle A is omitted in many handbooks, but it is a useful function and is found by subtracting $\cos A$ from unity: versin $A = 1.0000 - \cos A$.

Formulas for Circular Segments.— Referring to Fig. 354, we can derive the following formulas:

$$\frac{H}{B} = \frac{B}{X}, \qquad B^2 = HX,$$

$$X = \frac{B^2}{H}, \qquad H = R(\text{versin } A),$$

$$\text{versin } A = \frac{H}{R}, \qquad R = \frac{H + X}{2},$$

$$R = \frac{H}{\text{versin } A}, \qquad R = \frac{B^2 + H^2}{2H},$$

$$B = \sqrt{2HR - H^2}, \qquad B = \sin A \times R,$$

$$\sin A = \frac{B}{R}, \qquad H = R - \sqrt{R^2 - B^2},$$

$$E = R - H, \qquad E = \cos A \times R,$$

$$E = \sqrt{R^2 - B^2}.$$

Length of arc $L = 0.0174533 \times R \times L°$, in which the number of degrees in L is used as a whole number or a whole number and decimal fraction.
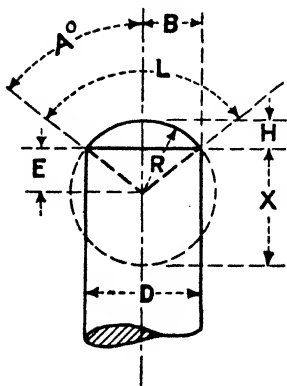
Fig. 354.—Illustrating many useful formulas.

Commonly Used Formulas.—If A represents any area and D is the diameter of any circle, then the diameter of a circle having the same area as any other given area is $D = 1.1284\sqrt{A}$; and by transposing terms and removing the radical sign $\sqrt{\ }$, we have $A = D^2/1.2733$. In common practice, the fourth decimal figure is dropped, and the formulas become $D = 1.128\sqrt{A}$, and $A = D^2/1.273$. These formulas are useful in computing the diameters of blanks for drawn shells and for finding the diameter of a circle whose area equals that of any given geometrical figure.

In Fig. 355, for a square: $A = 1.4142B$, $B = A/1.4142$,

$$A = B/0.70711,$$

$B = 0.70711A$, and the area $= B^2$.

For a regular hexagon, $C = 1.1547D$, and $D = C/1.1547$. Side $S = C/2$, and another formula is $S = 0.5773D$. Area $= 0.866 \times D^2$, or area $= 2.598 \times S^2$.

An octagon: $F = 1.0824E$, $E = F/1.0824$, $S = 0.3825F$, $S = 0.414E$, and the area $= 0.828 \times E^2$, or area $= 0.707 \times F^2$.

Area of a Circle Sector.—The area of the cross-sectioned surface, or the sector, shown in Fig. 356 is: area $= 0.008727N \times R^2$, in which

the number of degrees in N is used as a whole number or a whole number and a decimal fraction. The area of a circle segment, or the portion above line A-B, is the area of the sector minus the area of triangle A-B-C. Formulas for the length of D and for the height of the segment H are given under Fig. 354.
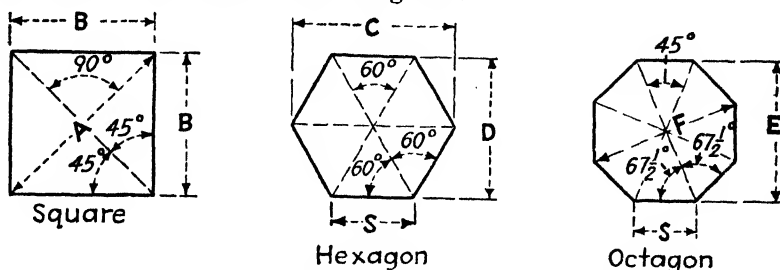
FIG. 355.—Illustrating several commonly used formulas.

The area of a spherical segment is $= 6.2832RH$. The volume of a spherical segment is $= 1.0472H^2(3R - H)$. The volume in terms of D is $= \pi H(D^2/8 + H^2/6)$.

Sphere.—If D is the diameter, R the radius, A the area, and V the volume of a sphere or ball: $A = \pi D^2$, and $V = 4.1888R^3$, or, in terms of D: $V = 0.5236D^3$.

Formulas for Cones.—In connection with Fig. 357 for a right circular cone: $S = \sqrt{r^2 + H^2}$, total area $= 1.5708DS$, or πrS,

$$\text{volume} = 1.0472r^2H,$$

area of base $= \pi \times r^2$, or $0.7854 \times D^2$.

Plane Ring.—In Fig. 357 the area of a plane circular ring

$$A = 0.7854(D^2 - d^2).$$

For a circular cylinder, when the area of its cross section is A, length L, and volume V: $V = A \times L$.

Torus, or Anchor Ring.—The areas of torus rings are often involved

FIG. 356.—A sector and segment of a circle. The segment is the portion above line A-B.

in computing drawn shells for culinary wares. They are used around the tops of finished cups or kettles and are then called "wiring rings." Area $= 9.87Dd$.

Cylindrical Shells.—For a square-cornered circular shell or cup (Fig. 357), area $A = \dfrac{d^2 + 4dh}{1.273}$. Since the diameter of a circle having

the same area as any other given area is $D = 1.128\sqrt{A}$ or $\sqrt{1.273A}$, then the formula for the diameter of blanks for square-cornered cylindrical shells is $D = \sqrt{d^2 + 4dh}$. By completing the square and transposing terms, the values for d and h are found:

$$d = \sqrt{(D^2 + 4h^2)} - 2h,$$

and $h = \dfrac{D^2 - d^2}{4d}$. These formulas apply to cylindrical shells in
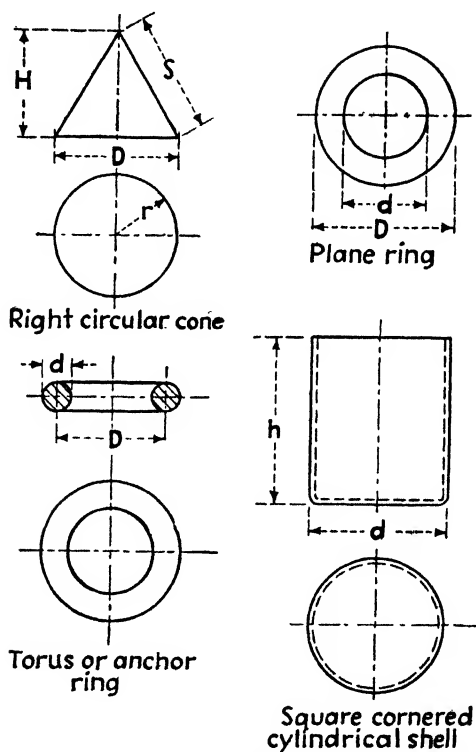
FIG. 357.—Illustrating several formulas used in pressworking of metals.

which there is no appreciable change in wall thickness incident to drawing. They are based on a condition in which the area of the drawn shell and the area of the blank are equal.

Tables giving blank diameters of cylindrical shells are computed by the foregoing formula. These tables are for shells having square corners. However, it is practically impossible to draw shells with square corners to any considerable depth, because the corners will fracture. Therefore, the tables simply establish quick calculations of blanks for shells with small corner radii. They are also an aid in

TABLE I.—APPROXIMATE BLANK DIAMETERS FOR CYLINDRICAL SHELLS

Height of shell, in.

Diameter of shell, in.	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2	2 1/4	2 1/2	2 3/4	3	3 1/4	3 1/2	3 3/4	4
1/4	0.75	0.83	0.90	0.97	1.03	1.09	1.15	1.20	1.25	1.30	1.34	1.39	1.43	1.52	1.59	1.67	1.75	1.82	1.89	1.95	2.02
3/8	0.94	1.04	1.13	1.21	1.28	1.34	1.42	1.48	1.55	1.61	1.67	1.71	1.78	1.88	1.98	2.07	2.16	2.24	2.32	2.40	2.48
1/2	1.12	1.22	1.32	1.41	1.50	1.58	1.66	1.73	1.80	1.87	1.93	2.00	2.07	2.18	2.29	2.39	2.50	2.60	2.69	2.78	2.88
5/8	1.28	1.40	1.50	1.60	1.70	1.79	1.88	1.96	2.04	2.11	2.19	2.26	2.32	2.46	2.58	2.69	2.80	2.92	3.02	3.12	3.23
3/4	1.44	1.56	1.67	1.78	1.89	1.98	2.08	2.16	2.25	2.33	2.41	2.48	2.56	2.70	2.84	2.96	3.09	3.21	3.32	3.43	3.54
7/8	1.59	1.72	1.84	1.95	2.06	2.16	2.26	2.36	2.45	2.54	2.62	2.70	2.78	2.94	3.08	3.22	3.38	3.50	3.63	3.75	3.84
1	1.73	1.87	2.00	2.12	2.23	2.34	2.45	2.55	2.64	2.74	2.82	2.91	3.00	3.16	3.31	3.46	3.61	3.74	3.87	4.00	4.13
1 1/8	1.87	2.02	2.15	2.28	2.40	2.51	2.62	2.73	2.83	2.93	3.02	3.11	3.21	3.37	3.53	3.69	3.84	3.98	4.12	4.26	4.39
1 1/4	2.01	2.16	2.30	2.43	2.56	2.68	2.80	2.90	3.01	3.11	3.22	3.31	3.40	3.58	3.75	3.91	4.07	4.22	4.37	4.51	4.65
1 3/8	2.16	2.31	2.45	2.59	2.72	2.84	2.96	3.08	3.18	3.29	3.39	3.49	3.59	3.77	3.95	4.12	4.28	4.44	4.59	4.74	4.88
1 1/2	2.29	2.45	2.60	2.74	2.87	3.00	3.12	3.24	3.36	3.46	3.58	3.67	3.77	3.97	4.15	4.33	4.50	4.66	4.82	4.97	5.12
1 5/8	2.42	2.59	2.74	2.89	3.02	3.15	3.28	3.40	3.52	3.63	3.74	3.85	3.95	4.15	4.34	4.53	4.70	4.87	5.03	5.20	5.35
1 3/4	2.56	2.72	2.88	3.03	3.17	3.30	3.43	3.56	3.68	3.80	3.91	4.03	4.14	4.34	4.54	4.73	4.90	5.08	5.25	5.42	5.57
1 7/8	2.70	2.86	3.02	3.18	3.32	3.46	3.59	3.72	3.84	3.97	4.08	4.20	4.30	4.52	4.71	4.91	5.10	5.28	5.45	5.62	5.79
2	2.83	3.00	3.16	3.31	3.46	3.61	3.75	3.87	4.00	4.12	4.24	4.36	4.47	4.69	4.90	5.10	5.29	5.48	5.65	5.83	6.00
2 1/8	2.96	3.13	3.30	3.46	3.61	3.75	3.89	4.02	4.16	4.28	4.40	4.52	4.64	4.86	5.08	5.28	5.48	5.67	5.85	6.03	6.21
2 1/4	3.09	3.27	3.44	3.60	3.75	3.90	4.04	4.18	4.31	4.44	4.56	4.68	4.80	5.03	5.25	5.46	5.66	5.86	6.05	6.23	6.41
2 3/8	3.22	3.40	3.57	3.74	3.89	4.04	4.18	4.32	4.46	4.59	4.72	4.84	4.96	5.20	5.42	5.64	5.84	6.04	6.24	6.42	6.61
2 1/2	3.35	3.54	3.71	3.87	4.03	4.18	4.33	4.47	4.61	4.74	4.87	5.00	5.12	5.36	5.59	5.81	6.02	6.22	6.42	6.61	6.80
2 5/8	3.48	3.67	3.84	4.01	4.17	4.32	4.47	4.62	4.76	4.89	5.03	5.15	5.28	5.52	5.76	5.98	6.20	6.40	6.61	6.80	6.99
2 3/4	3.61	3.80	3.98	4.15	4.31	4.47	4.62	4.76	4.90	5.04	5.18	5.31	5.44	5.68	5.92	6.15	6.37	6.58	6.79	6.99	7.18
2 7/8	3.75	3.93	4.11	4.28	4.45	4.60	4.76	4.91	5.05	5.19	5.33	5.46	5.59	5.84	6.08	6.32	6.54	6.76	6.96	7.17	7.37
3	3.87	4.06	4.24	4.42	4.58	4.74	4.90	5.05	5.20	5.34	5.48	5.61	5.74	6.00	6.25	6.48	6.71	6.93	7.14	7.35	7.55
3 1/8	4.00	4.19	4.38	4.55	4.72	4.88	5.04	5.19	5.34	5.48	5.63	5.76	5.90	6.16	6.40	6.64	6.87	7.10	7.32	7.52	7.73
3 1/4	4.13	4.32	4.51	4.68	4.85	5.02	5.18	5.33	5.48	5.63	5.77	5.91	6.05	6.31	6.56	6.80	7.04	7.26	7.48	7.70	7.91
3 3/8	4.26	4.45	4.64	4.82	4.99	5.15	5.31	5.47	5.62	5.77	5.92	6.05	6.19	6.47	6.72	6.96	7.20	7.43	7.66	7.87	8.08
3 1/2	4.39	4.58	4.77	4.95	5.12	5.29	5.45	5.61	5.77	5.91	6.06	6.20	6.35	6.61	6.87	7.12	7.37	7.60	7.83	8.05	8.26
3 5/8	4.51	4.71	4.90	5.08	5.26	5.43	5.59	5.75	5.90	6.06	6.21	6.35	6.49	6.76	7.03	7.28	7.52	7.76	7.99	8.21	8.43
3 3/4	4.64	4.84	5.03	5.21	5.39	5.56	5.73	5.89	6.04	6.20	6.35	6.49	6.63	6.91	7.18	7.43	7.68	7.92	8.16	8.38	8.60
3 7/8	4.77	4.97	5.16	5.34	5.52	5.69	5.86	6.02	6.18	6.34	6.49	6.64	6.78	7.06	7.33	7.59	7.84	8.08	8.32	8.55	8.77
4	4.90	5.10	5.29	5.48	5.66	5.83	6.00	6.16	6.32	6.48	6.63	6.78	6.92	7.21	7.48	7.74	8.00	8.24	8.48	8.71	8.94
4 1/8	5.02	5.22	5.42	5.61	5.79	5.96	6.13	6.30	6.46	6.62	6.77	6.92	7.07	7.36	7.63	7.89	8.15	8.40	8.64	8.88	9.11
4 1/4	5.15	5.35	5.55	5.74	5.92	6.09	6.27	6.43	6.60	6.76	6.91	7.06	7.21	7.50	7.78	8.05	8.31	8.56	8.80	9.04	9.27
4 3/8	5.28	5.48	5.68	5.87	6.05	6.23	6.40	6.57	6.73	6.89	7.05	7.21	7.35	7.64	7.93	8.20	8.46	8.71	8.96	9.20	9.44
4 1/2	5.40	5.61	5.81	6.00	6.18	6.36	6.53	6.70	6.87	7.03	7.19	7.35	7.50	7.79	8.07	8.35	8.61	8.87	9.12	9.38	9.60

TABLE I.—APPROXIMATE BLANK DIAMETERS FOR CYLINDRICAL SHELLS.—(Continued)

Height of shell, in.

Diameter of shell, in.	½	⅝	¾	⅞	1	1⅛	1¼	1⅜	1½	1⅝	1¾	1⅞	2	2¼	2½	2¾	3	3¼	3½	3¾	4
4⅝	5.53	5.74	5.93	6.13	6.31	6.49	6.67	6.84	7.01	7.17	7.33	7.48	7.64	7.93	8.22	8.50	8.76	9.02	9.28	9.52	9.76
4¾	5.66	5.86	6.06	6.26	6.44	6.62	6.80	6.97	7.14	7.31	7.47	7.62	7.78	8.08	8.37	8.64	8.91	9.18	9.43	9.68	9.92
4⅞	5.78	5.99	6.19	6.39	6.57	6.76	6.93	7.11	7.28	7.44	7.60	7.76	7.92	8.22	8.51	8.79	9.07	9.33	9.59	9.84	10.08
5	5.91	6.12	6.32	6.52	6.70	6.89	7.07	7.24	7.41	7.58	7.74	7.90	8.06	8.36	8.66	8.94	9.21	9.48	9.74	10.00	10.24
5⅛	6.04	6.25	6.45	6.64	6.83	7.02	7.20	7.37	7.55	7.72	7.88	8.04	8.21	8.51	8.80	9.09	9.37	9.63	9.90	10.15	10.40
5¼	6.17	6.37	6.58	6.77	6.96	7.15	7.33	7.51	7.68	7.85	8.02	8.18	8.34	8.65	8.94	9.23	9.51	9.78	10.05	10.31	10.56
5⅜	6.29	6.50	6.71	6.90	7.09	7.28	7.46	7.64	7.82	7.99	8.15	8.31	8.48	8.79	9.09	9.38	9.66	9.93	10.20	10.46	10.72
5½	6.42	6.63	6.83	7.03	7.22	7.41	7.60	7.77	7.95	8.12	8.29	8.45	8.61	8.93	9.23	9.52	9.81	10.08	10.35	10.62	10.87
5⅝	6.54	6.76	6.96	7.16	7.35	7.54	7.73	7.91	8.08	8.25	8.42	8.59	8.75	9.07	9.37	9.67	9.95	10.23	10.50	10.77	11.02
5¾	6.67	6.88	7.09	7.29	7.48	7.67	7.86	8.04	8.22	8.39	8.56	8.72	8.89	9.20	9.51	9.81	10.10	10.38	10.65	10.92	11.18
5⅞	6.80	7.01	7.22	7.42	7.61	7.80	7.99	8.17	8.35	8.52	8.69	8.86	9.02	9.34	9.65	9.95	10.24	10.52	10.80	11.07	11.33
6	6.92	7.14	7.34	7.55	7.74	7.93	8.12	8.30	8.48	8.66	8.83	9.00	9.16	9.48	9.79	10.09	10.39	10.67	10.95	11.22	11.48
6¼	7.18	7.39	7.60	7.80	8.00	8.19	8.38	8.57	8.75	8.92	9.10	9.27	9.44	9.76	10.07	10.38	10.68	10.96	11.25	11.52	11.79
6½	7.43	7.64	7.85	8.06	8.26	8.45	8.64	8.83	9.01	9.19	9.36	9.54	9.71	10.03	10.35	10.66	10.96	11.25	11.54	11.82	12.09
6¾	7.68	7.90	8.11	8.31	8.51	8.71	8.90	9.09	9.27	9.45	9.63	9.80	9.97	10.31	10.63	10.94	11.25	11.54	11.83	12.11	12.39
7	7.93	8.15	8.36	8.57	8.77	8.97	9.16	9.35	9.53	9.72	9.89	10.07	10.24	10.58	10.90	11.22	11.53	11.83	12.12	12.40	12.68
7¼	8.18	8.40	8.62	8.82	9.03	9.22	9.42	9.61	9.80	9.98	10.16	10.34	10.51	10.85	11.18	11.50	11.81	12.11	12.41	12.70	12.98
7½	8.44	8.66	8.87	9.08	9.28	9.48	9.68	9.87	10.06	10.24	10.42	10.60	10.78	11.12	11.45	11.77	12.09	12.39	12.69	12.99	13.27
7¾	8.69	8.91	9.12	9.33	9.54	9.74	9.94	10.13	10.32	10.50	10.69	10.87	11.04	11.39	11.72	12.05	12.37	12.68	12.98	13.27	13.56
8	8.94	9.16	9.38	9.59	9.79	10.00	10.19	10.39	10.58	10.77	10.95	11.13	11.31	11.66	11.99	12.32	12.64	12.96	13.26	13.56	13.85
8¼	9.19	9.41	9.63	9.84	10.05	10.25	10.45	10.65	10.84	11.03	11.21	11.39	11.57	11.92	12.27	12.60	12.92	13.23	13.54	13.84	14.14
8½	9.44	9.66	9.88	10.10	10.30	10.51	10.71	10.90	11.10	11.29	11.47	11.66	11.84	12.19	12.53	12.87	13.20	13.51	13.82	14.13	14.43
8¾	9.69	9.92	10.13	10.35	10.56	10.76	10.96	11.16	11.36	11.55	11.73	11.92	12.10	12.46	12.80	13.14	13.47	13.79	14.10	14.41	14.71
9	9.95	10.17	10.39	10.60	10.81	11.02	11.21	11.42	11.61	11.81	11.99	12.18	12.36	12.72	13.07	13.41	13.74	14.07	14.38	14.69	14.99
9¼	10.20	10.42	10.64	10.85	11.07	11.27	11.48	11.68	11.87	12.07	12.26	12.44	12.63	12.99	13.34	13.68	14.02	14.34	14.66	14.97	15.28
9½	10.45	10.67	10.89	11.11	11.32	11.53	11.73	11.93	12.13	12.32	12.52	12.70	12.89	13.25	13.61	13.95	14.29	14.61	14.94	15.25	15.56
9¾	10.70	10.92	11.14	11.36	11.57	11.78	11.99	12.19	12.39	12.58	12.77	12.96	13.15	13.52	13.87	14.22	14.56	14.89	15.21	15.53	15.84
10	10.95	11.18	11.40	11.61	11.83	12.04	12.24	12.44	12.64	12.84	13.03	13.22	13.41	13.78	14.14	14.49	14.83	15.16	15.49	15.81	16.12
10¼	11.20	11.43	11.65	11.87	12.08	12.29	12.50	12.70	12.90	13.10	13.29	13.48	13.67	14.04	14.40	14.75	15.10	15.43	15.76	16.08	16.40
10½	11.45	11.68	11.90	12.12	12.33	12.54	12.75	12.96	13.16	13.36	13.55	13.74	13.93	14.30	14.66	15.02	15.36	15.70	16.03	16.36	16.68
10¾	11.70	11.93	12.15	12.37	12.59	12.80	13.01	13.21	13.41	13.61	13.81	14.00	14.19	14.56	14.93	15.29	15.63	15.97	16.31	16.63	16.95
11	11.95	12.18	12.40	12.62	12.84	13.05	13.26	13.47	13.67	13.87	14.07	14.26	14.45	14.83	15.19	15.55	15.90	16.24	16.58	16.91	17.22
11¼	12.20	12.43	12.66	12.88	13.09	13.30	13.52	13.72	13.93	14.13	14.33	14.52	14.71	15.08	15.46	15.82	16.17	16.52	16.84	17.17	17.50
11½	12.45	12.65	12.91	13.13	13.35	13.56	13.77	13.98	14.18	14.38	14.58	14.78	14.97	15.35	15.72	16.08	16.43	16.78	17.11	17.45	17.78
11¾	12.66	12.92	13.16	13.38	13.59	13.82	14.03	14.23	14.43	14.63	14.84	15.04	15.22	15.60	15.98	16.34	16.70	17.05	17.39	17.73	18.05
12	12.96	13.20	13.41	13.63	13.86	14.07	14.28	14.49	14.70	14.88	15.10	15.30	15.50	15.88	16.24	16.61	16.96	17.32	17.66	18.00	18.33

TABLE I.—APPROXIMATE BLANK DIAMETERS FOR CYLINDRICAL SHELLS.—*(Continued)*

Height of shell, in.

Diameter of shell, in.	4¼	4½	4¾	5	5¼	5½	5¾	6	6½	7	7½	8	8½	9	9½	10	10½	11	11½	12
¼	2.08	2.13	2.20	2.25	2.31	2.33	2.41	2.46	2.56	2.66	2.75	2.83	2.93	3.01	3.09	3.17	3.25	3.33	3.40	3.48
⅜	2.55	2.63	2.70	2.76	2.83	2.90	2.96	3.03	3.15	3.27	3.38	3.48	3.58	3.70	3.80	3.90	3.98	4.08	4.17	4.26
½	2.96	3.04	3.12	3.20	3.28	3.35	3.42	3.50	3.64	3.77	3.90	4.03	4.15	4.27	4.39	4.50	4.61	4.71	4.82	4.93
⅝	3.32	3.42	3.50	3.59	3.68	3.76	3.84	3.92	4.08	4.23	4.38	4.52	4.65	4.78	4.91	5.04	5.16	5.28	5.39	5.51
¾	3.65	3.75	3.85	3.94	4.03	4.13	4.22	4.30	4.48	4.64	4.80	4.96	5.10	5.25	5.39	5.53	5.66	5.79	5.92	6.05
⅞	3.95	4.06	4.17	4.27	4.39	4.47	4.57	4.66	4.84	5.03	5.19	5.36	5.52	5.68	5.83	5.98	6.12	6.26	6.40	6.53
1	4.24	4.35	4.46	4.58	4.63	4.79	4.89	5.00	5.19	5.39	5.57	5.74	5.92	6.08	6.21	6.40	6.56	6.71	6.86	7.00
1⅛	4.51	4.63	4.75	4.87	4.98	5.10	5.21	5.31	5.52	5.72	5.92	6.10	6.29	6.46	6.63	6.80	6.96	7.12	7.28	7.43
1¼	4.78	4.90	5.03	5.15	5.27	5.39	5.50	5.61	5.84	6.04	6.25	6.45	6.64	6.82	7.00	7.18	7.35	7.52	7.68	7.84
1⅜	5.02	5.16	5.29	5.42	5.54	5.67	5.79	5.90	6.13	6.35	6.57	6.78	6.97	7.16	7.35	7.54	7.73	7.89	8.07	8.24
1½	5.26	5.40	5.54	5.68	5.81	5.93	6.07	6.19	6.42	6.65	6.87	7.09	7.30	7.50	7.70	7.89	8.08	8.26	8.44	8.62
1⅝	5.50	5.64	5.78	5.92	6.06	6.20	6.33	6.45	6.70	6.94	7.17	7.39	7.61	7.82	8.02	8.22	8.42	8.61	8.80	8.98
1¾	5.72	5.88	6.02	6.17	6.31	6.45	6.58	6.71	6.97	7.22	7.46	7.69	7.91	8.13	8.34	8.55	8.75	8.95	9.14	9.33
1⅞	5.95	6.10	6.25	6.41	6.55	6.69	6.83	6.96	7.23	7.49	7.73	7.97	8.20	8.43	8.64	8.85	9.07	9.27	9.48	9.67
2	6.16	6.32	6.48	6.63	6.78	6.93	7.07	7.21	7.49	7.75	8.00	8.25	8.48	8.72	8.94	9.17	9.38	9.59	9.80	10.00
2¼	6.38	6.54	6.70	6.86	7.01	7.16	7.31	7.45	7.73	8.00	8.26	8.52	8.76	9.00	9.23	9.46	9.68	9.90	10.11	10.32
2⅜	6.58	6.75	6.91	7.08	7.23	7.39	7.54	7.68	7.97	8.25	8.52	8.78	9.03	9.28	9.52	9.75	9.93	10.21	10.42	10.63
2½	6.78	6.96	7.13	7.29	7.45	7.61	7.76	7.91	8.21	8.49	8.77	9.03	9.29	9.55	9.79	10.03	10.26	10.49	10.72	10.94
2⅝	6.98	7.16	7.33	7.50	7.66	7.82	7.98	8.14	8.44	8.73	9.01	9.29	9.55	9.81	10.03	10.31	10.55	10.78	11.01	11.24
2¾	7.18	7.36	7.53	7.71	7.88	8.04	8.20	8.36	8.67	8.97	9.25	9.53	9.80	10.07	10.33	10.58	10.82	11.06	11.30	11.53
2⅞	7.37	7.55	7.73	7.91	8.08	8.25	8.41	8.58	8.89	9.20	9.49	9.78	10.05	10.32	10.59	10.84	11.09	11.33	11.58	11.81
3	7.56	7.75	7.93	8.11	8.29	8.46	8.62	8.79	9.11	9.42	9.72	10.01	10.29	10.57	10.84	11.11	11.35	11.61	11.85	12.09
3⅛	7.75	7.94	8.12	8.30	8.48	8.66	8.83	9.00	9.33	9.64	9.95	10.25	10.53	10.82	11.03	11.35	11.62	11.87	12.12	12.37
3¼	7.93	8.12	8.31	8.50	8.68	8.86	9.03	9.20	9.54	9.86	10.17	10.48	10.77	11.03	11.34	11.61	11.83	12.13	12.39	12.64
3⅜	8.11	8.31	8.50	8.69	8.88	9.06	9.23	9.41	9.75	10.03	10.40	10.70	11.00	11.29	11.58	11.86	12.13	12.39	12.65	12.90
3½	8.29	8.49	8.69	8.88	9.07	9.25	9.43	9.61	9.96	10.29	10.61	10.93	11.23	11.53	11.82	12.10	12.37	12.64	12.91	13.17
3⅝	8.47	8.68	8.87	9.06	9.26	9.45	9.63	9.81	10.16	10.50	10.83	11.15	11.46	11.76	12.05	12.34	12.62	12.89	13.16	13.43
3¾	8.65	8.85	9.06	9.25	9.45	9.64	9.82	10.00	10.36	10.71	11.04	11.36	11.68	11.98	12.28	12.57	12.86	13.14	13.41	13.68
3⅞	8.82	9.03	9.23	9.44	9.63	9.82	10.01	10.20	10.56	10.91	11.25	11.58	11.90	12.21	12.51	12.80	13.09	13.37	13.65	13.93
4	8.99	9.20	9.41	9.61	9.82	10.01	10.20	10.39	10.76	11.11	11.45	11.79	12.11	12.43	12.74	13.04	13.33	13.62	13.90	14.18
4¼	9.16	9.38	9.59	9.79	10.00	10.20	10.39	10.58	10.95	11.31	11.66	12.00	12.33	12.65	12.96	13.26	13.56	13.85	14.14	14.42
4½	9.33	9.55	9.76	9.97	10.18	10.38	10.57	10.76	11.14	11.51	11.86	12.20	12.54	12.86	13.18	13.49	13.79	14.09	14.38	14.66
4¾	9.50	9.72	9.94	10.15	10.35	10.56	10.76	10.95	11.33	11.7	12.06	12.41	12.75	13.07	13.40	13.72	14.02	14.32	14.61	14.90
5	9.67	9.89	10.11	10.32	10.53	10.74	10.94	11.14	11.52	11.90	12.26	12.61	12.95	13.29	13.61	13.93	14.24	14.54	14.84	15.13
5½	9.83	10.06	10.28	10.50	10.71	10.92	11.12	11.32	11.71	12.09	12.45	12.81	13.16	13.50	13.92	14.15	14.45	14.77	15.07	15.37

TABLE I.—APPROXIMATE BLANK DIAMETERS FOR CYLINDRICAL SHELLS.—(*Continued*)

Diameter of shell, in.	Height of shell, in.																			
	4¼	4½	4¾	5	5¼	5½	5¾	6	6½	7	7½	8	8½	9	9½	10	10½	11	11½	12
4⅝	10.00	10.22	10.45	10.67	10.88	11.09	11.30	11.50	11.90	12.28	12.65	13.01	13.36	13.70	14.04	14.36	14.68	14.99	15.30	15.60
4¾	10.16	10.39	10.62	10.84	11.05	11.27	11.47	11.68	12.08	12.47	12.84	13.21	13.56	13.91	14.25	14.57	14.90	15.22	15.52	15.83
4⅞	10.32	10.55	10.78	11.01	11.23	11.44	11.65	11.85	12.26	12.65	13.03	13.41	13.76	14.11	14.45	14.79	15.11	15.43	15.74	16.05
5	10.49	10.72	10.95	11.18	11.40	11.61	11.83	12.04	12.45	12.84	13.23	13.60	13.95	14.32	14.65	15.00	15.33	15.65	15.97	16.23
5⅛	10.65	10.88	11.12	11.34	11.57	11.79	12.00	12.21	12.63	13.03	13.41	13.79	14.16	14.52	14.86	15.21	15.54	15.87	16.19	16.50
5¼	10.80	11.04	11.28	11.51	11.74	11.96	12.17	12.38	12.81	13.21	13.60	13.98	14.35	14.71	15.07	15.41	15.75	16.08	16.40	16.72
5⅜	10.96	11.20	11.44	11.68	11.90	12.13	12.35	12.55	12.93	13.33	13.79	14.17	14.54	14.91	15.27	15.61	15.95	16.29	16.61	16.93
5½	11.12	11.36	11.60	11.84	12.07	12.29	12.52	12.73	13.16	13.57	13.97	14.36	14.73	15.11	15.46	15.82	16.16	16.50	16.83	17.15
5⅝	11.28	11.52	11.76	12.00	12.24	12.46	12.69	12.90	13.33	13.75	14.15	14.54	14.93	15.30	15.66	16.02	16.36	16.70	17.04	17.36
5¾	11.43	11.68	11.92	12.16	12.40	12.63	12.85	13.07	13.51	13.93	14.33	14.73	15.11	15.49	15.86	16.21	16.57	16.91	17.25	17.58
5⅞	11.59	11.84	12.08	12.32	12.56	12.79	13.02	13.24	13.68	14.10	14.51	14.91	15.30	15.68	16.05	16.41	16.77	17.11	17.45	17.79
6	11.74	12.00	12.24	12.49	12.72	12.96	13.19	13.41	13.85	14.28	14.69	15.09	15.49	15.87	16.24	16.61	16.97	17.32	17.66	18.00
6¼	12.05	12.31	12.56	12.81	13.04	13.28	13.52	13.75	14.19	14.63	15.05	15.46	15.86	16.24	16.63	17.00	17.36	17.72	18.07	18.41
6½	12.36	12.61	12.87	13.12	13.37	13.61	13.84	14.08	14.53	14.97	15.40	15.81	16.22	16.62	17.00	17.38	17.75	18.11	18.47	18.82
6¾	12.66	12.92	13.18	13.43	13.68	13.93	14.17	14.40	14.86	15.31	15.74	16.17	16.58	16.98	17.37	17.76	18.14	18.50	18.86	19.22
7	12.96	13.21	13.49	13.74	14.00	14.24	14.49	14.73	15.19	15.65	16.09	16.52	16.94	17.34	17.74	18.13	18.52	18.89	19.26	19.62
7¼	13.25	13.52	13.79	14.05	14.31	14.56	14.80	15.05	15.52	15.98	16.43	16.86	17.29	17.70	18.11	18.51	18.89	19.27	19.64	20.01
7½	13.55	13.82	14.09	14.36	14.62	14.87	15.12	15.37	15.85	16.31	16.77	17.21	17.64	18.06	18.47	18.87	19.26	19.65	20.03	20.40
7¾	13.84	14.12	14.39	14.66	14.92	15.18	15.43	15.68	16.17	16.64	17.10	17.55	17.98	18.41	18.82	19.23	19.63	20.02	20.40	20.78
8	14.14	14.42	14.69	14.96	15.23	15.49	15.74	16.00	16.49	16.97	17.43	17.88	18.33	18.76	19.18	19.59	20.00	20.39	20.78	21.16
8¼	14.43	14.71	14.99	15.26	15.53	15.79	16.05	16.31	16.80	17.29	17.76	18.22	18.67	19.10	19.53	19.95	20.36	20.76	21.15	21.54
8½	14.72	15.00	15.28	15.56	15.83	16.10	16.36	16.62	17.12	17.61	18.09	18.55	19.00	19.44	19.88	20.30	20.71	21.12	21.52	21.91
8¾	15.00	15.29	15.58	15.86	16.13	16.40	16.66	16.92	17.40	17.90	18.38	18.85	19.31	19.76	20.20	20.62	21.04	21.46	21.86	22.26
9	15.29	15.58	15.87	16.15	16.43	16.70	16.97	17.23	17.74	18.24	18.73	19.20	19.67	20.12	20.56	21.00	21.42	21.84	22.24	22.64
9¼	15.58	15.87	16.16	16.44	16.72	17.00	17.27	17.53	18.05	18.56	19.05	19.53	20.00	20.45	20.90	21.34	21.77	22.19	22.60	23.01
9½	15.86	16.16	16.45	16.74	17.02	17.29	17.57	17.83	18.36	18.87	19.37	19.85	20.32	20.79	21.24	21.68	22.11	22.54	22.96	23.37
9¾	16.14	16.44	16.74	17.03	17.31	17.59	17.86	18.14	18.67	19.18	19.68	20.17	20.65	21.12	21.57	22.02	22.46	22.89	23.31	23.72
10	16.43	16.73	17.02	17.32	17.60	17.88	18.16	18.43	18.97	19.49	20.00	20.49	20.97	21.44	21.90	22.36	22.80	23.23	23.66	24.08
10¼	16.71	17.01	17.31	17.60	17.89	18.18	18.46	18.73	19.27	19.80	20.31	20.81	21.29	21.77	22.24	22.69	23.14	23.58	24.01	24.43
10½	16.99	17.29	17.59	17.89	18.18	18.47	18.75	19.03	19.57	20.10	20.62	21.12	21.61	22.09	22.56	23.02	23.47	23.92	24.35	24.78
10¾	17.27	17.58	17.88	18.18	18.47	18.76	19.04	19.32	19.87	20.40	20.92	21.43	21.93	22.42	22.89	23.35	23.81	24.26	24.69	25.13
11	17.55	17.86	18.16	18.46	18.76	19.05	19.33	19.62	20.17	20.71	21.23	21.74	22.24	22.73	23.21	23.68	24.14	24.59	25.03	25.47
11¼	17.81	18.14	18.44	18.74	19.04	19.34	19.63	19.91	20.47	21.01	21.54	22.05	22.56	23.05	23.53	24.01	24.47	24.93	25.37	25.82
11½	18.09	18.41	18.72	19.03	19.33	19.62	19.91	20.20	20.76	21.31	21.84	22.36	22.87	23.37	23.85	24.33	24.80	25.26	25.70	26.15
11¾	18.38	18.70	19.01	19.32	19.63	19.92	20.21	20.50	21.05	21.61	22.14	22.67	23.18	23.68	24.17	24.66	25.13	25.58	26.04	26.49
12	18.64	18.97	19.28	19.59	19.89	20.20	20.49	20.77	21.35	21.90	22.45	22.97	23.50	23.99	24.48	24.97	25.45	25.93	26.37	26.84
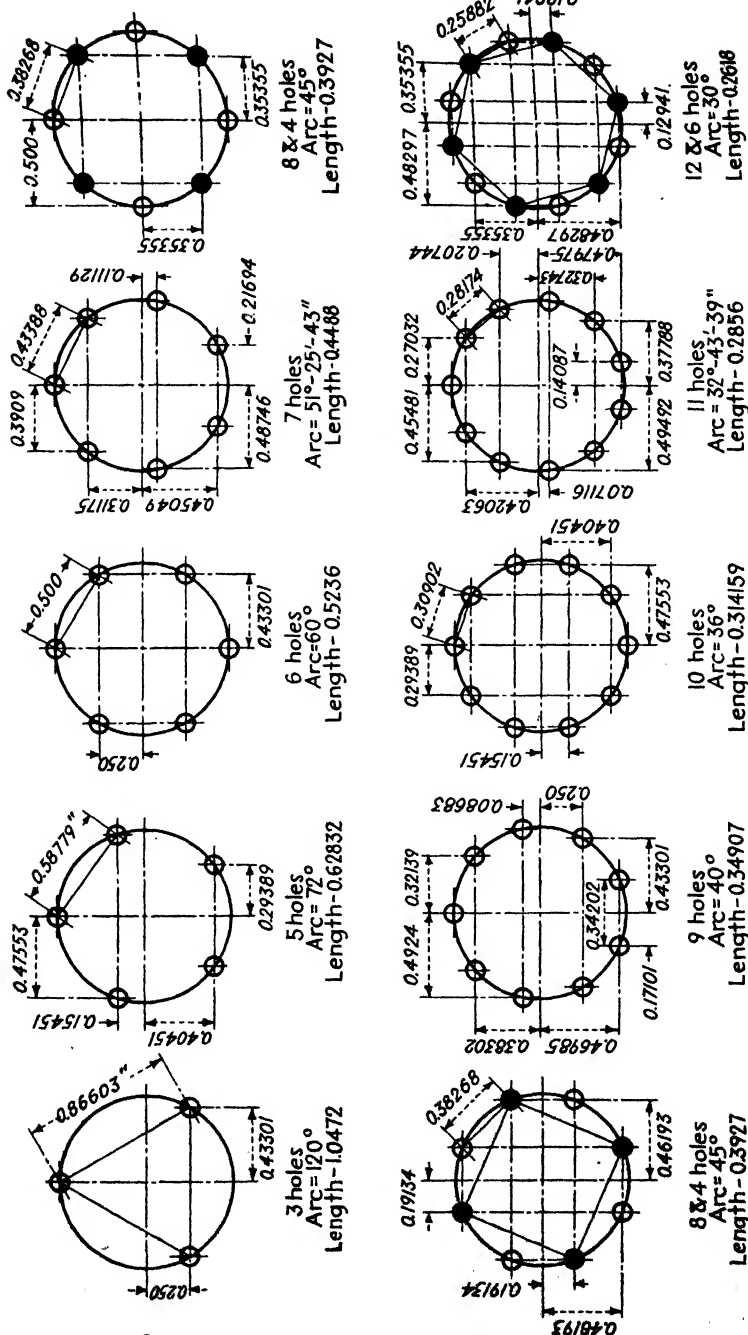
Fig. 358.—Dimensions between equally spaced centers on circles of 1 in. in diameter.

the computation of blank diameters for shells of larger radii and are a correct standard upon which to base general calculations.

When determining the blank diameters for drawn shells, it is always assumed that the work has no thickness. In other words, the shell is computed along an imaginary neutral line in the material located at half the stock thickness. This fact should be remembered in all considerations of shell diameters. When d is the diameter and t the wall thickness, d is the outside diameter of the shell minus t.

It has been said that to predetermine accurately the blank sizes for drawn shells is impossible, that an attempt to figure them is simply wasting time because the diemaker can develop the blanks by trial. On the other hand, in estimating the costs of dies for determining the necessary shearing widths and blanking centers and costs of materials and the size and cost of the blanking die, it is very necessary to be able to predetermine the shapes, sizes, or diameters of blanks. If a contract shop is unable to figure shell-blank diameters, it would be a losing business for them to continue taking orders for blanking and drawing tools.

The tables of Approximate Blank Diameters for Cylindrical Shells, shown on pages 395–398, published by permission of E. W. Bliss Co., are based on the foregoing formula

$$D = \sqrt{d^2 + 4dh}.$$

Thinning or thickening of the shell walls or stretching the shells, all of which are sometimes necessary for special purposes, are features not covered in these tables. The figures given are for blank diameters with areas the same as those of the finished shells. All the tabulated shells have square corners.

Changing Circular Dimensions to Vertical and Horizontal.—This change is often desirable when jig boring holes in dies, jigs, fixtures, and other work. So-called "straight dimensions" are easier to make a setup for jig-boring, than setting up the circular attachment on the machine. It is also easier for the designer in giving his dimensions.

In Fig. 358 are 13 cases in which all the necessary dimensions between equally spaced centers are worked out for circles 1 in. in diameter. To find the straight dimensions, chords, or length of arcs in any given circle, multiply the values shown in Fig. 358 by the diameter of the given circle.

JIG-BORING HOLES FOR DIES AND DIE OPENINGS

Boring Holes for Die Openings.—The contour openings in blanking dies are of shapes similar to well-known geometrical figures. They

usually consist of circular arcs at corners, with straight- or curved-line connections between. A jig-boring machine is the equipment used for boring the "sweeps" of arcs at inside corners and at the same time removing some of the steel within the die opening.

In jig boring progressive dies, other advantages are also obtained. Holes or openings at multiple stations in the block can be bored at the same setting as the blanking die. Thus we have the exact blank-ing-center distance established relative to the die opening and to other groups of holes from station to station. The great accuracy of these machines is another advantage. Holes can be bored within limits of less than one quarter of a thousandth inch variation between centers.

In angular corners of die openings, holes are bored with circum-ferences touching the adjacent sides of the corners. Subsequently, the die opening is roughed out on a band saw and vertical shaper and then "file finished" to line.

"Stepped Dimensions."—This type of dimensioning tool drawings was adopted primarily to suit jig-boring operations. The advantages in using this system are several. Dimensions are each given from common lines called "zero lines" and to each of the hole centers. Like a system of rectangular coordinates, the dimensions are given from the upper edge of the die block *down* to each center, and from the left edge of the block toward the right to each center. For symmetrically shaped work, the center lines of the die opening are used for the zero lines. In such cases dimensions are given from both sides of the lines to each hole center. An example that sets forth this system of giving dimensions is illustrated in Fig. 321.

Step dimensioning not only avoids unnecessary figuring in the shop but eliminates the cumulative errors that always arise when dimen-sions are given from center to center. It permits changing any of the individual dimensions without interfering with the others. If stepped dimensions are not given as outlined above and as indicated in Fig. 147, the work setting will be positioned wrong on the machine. It will fail to correspond with the fixed directions of table feeds and will require extra time for refiguring.

Solving Oblique Triangles.—When the three sides A, B, and C are known (Fig. 359) and the unknown dimensions are to be solved, lay out and letter the triangle as shown, and proceed to determine dimension Z. The formula used is $Z = \dfrac{A^2 - B^2}{2C}$. It is apparent that when Z is solved, all the remaining unknown dimensions can be found. The need for this formula often arises in locating centers for

boring holes in dies, for bushing holes in drilling jigs, and for general tool engineering.

Locating Jig-boring Centers.—One example of this is seen in Fig. 360. Given angle A and dimensions C, to find dimensions x. After determining the bored diameter of holes H, so that the circumferences
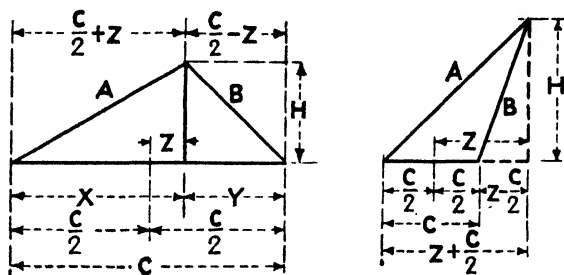
FIG. 359.—Illustrating the formula for solving Z, X, Y, H, and all the angles, given the three sides A, B, and C.

of H and D will not cut into each other, $r = H/2$, $b = \text{cotan } A \times r$, and $x = C - b$.

The centers of outside radii are drilled and reamed with $\frac{1}{16}$-in. diameter holes E. A hardened circular button is subsequently made, with a radius of R and with a center shoulder stud $\frac{1}{16}$ in. in diameter. The stud is then located in holes E, for filing the radius R within the die opening.
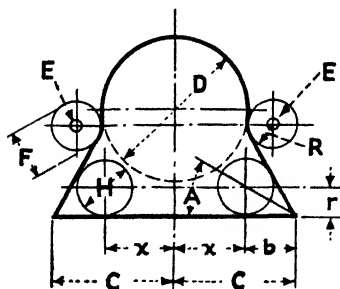
FIG. 360.—In a die opening of this shape, dimensions x are to be found, given angle A, diameter H, and dimensions C.

Where punch clearance is involved, the over-all die clearance is added to the diameters of H and D, but it is subtracted from diameter F, while dimensions x remain the same. In this way the edges of the die are moved out one half the over-all die clearance all around the opening.

Circular-arc Dimensions.—Figure 361 illustrates the method for giving circular stepped dimensions. The steps are continued until the last hole A is included. However, above 15 holes this system becomes too complicated to put on a drawing. When many holes are involved, it is customary to tabulate the dimensions below the sketch. Cases where two or three hundred holes are to be located and the multiple is in degrees, minutes, and seconds will give the tool engineer plenty of figuring, especially if some of the holes are not equally spaced.

In Fig. 362 for the diameter of an inscribed bored hole touching three sides of an opening and enclosed within 45-deg. angles,

$$D = C \times 2.4142.$$

For the diameter of a bored hole similarly inscribed within any equal angles (Fig. 363), $D = \cotan \dfrac{A}{2} \times C$. For an inscribed bored hole touching three sides and confined between unequal angles (Fig. 364),

$$D = \frac{2C}{\cotan A + \cotan B}.$$

In any right-angled triangle (Fig. 365), $D = (a + b) - c$. To locate a hole center so that its circumference is tangent to a straight line and tangent within an arc of a circle (Fig. 366), $C = R - r$, $B = \sqrt{C^2 - A^2}$, and $x = R - B$.
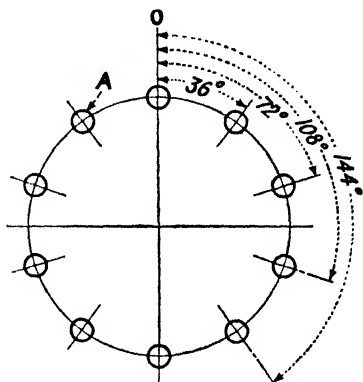
Fig. 361.—Method of giving stepped dimensions for circular arcs.
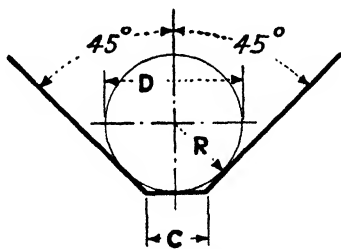
Fig. 362.
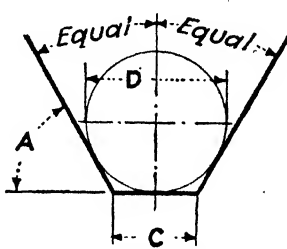
Fig. 363.
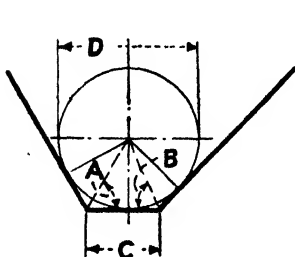
Fig. 364.
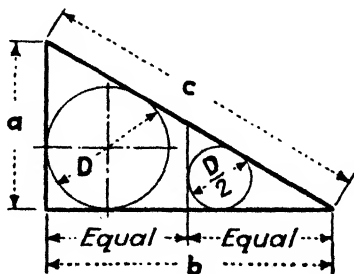
Fig. 365.

In Fig. 367 we have given the three sides of any triangle to determine the inscribed diameter of a bored hole D. First, find any two angles, as A and B. Since the center of a circle inscribed within any

triangle is at the point of intersection of straight lines that bisect any two of its angles, then angle $x = \dfrac{A}{2}$, and $y = \dfrac{B}{2}$.

$$D = \frac{2c}{\cotan x + \cotan y}.$$

Determining Straight Dimensions for Triangles.—Given three sides a, b, and c of any triangle (Fig. 368) and the radius of three suitable holes for jig boring the angles, find the straight dimensions,
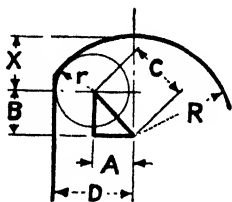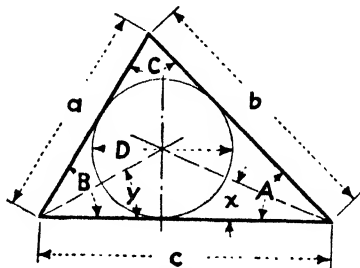
FIG. 366.   FIG. 367.
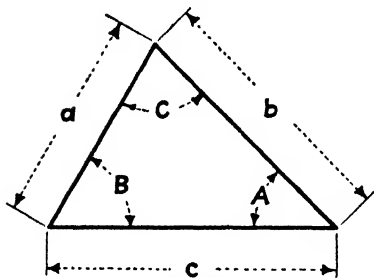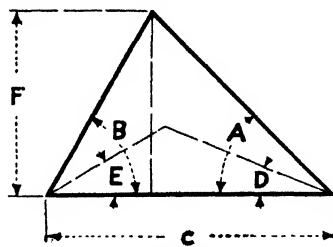
FIG. 368.   FIG. 369.

which are those parallel to and at right angles with base c, and which determine the locations of the hole centers.

Solution: First determine the angles A and B. Draw Fig. 369, in which $D = \dfrac{A}{2}$ and $E = \dfrac{B}{2}$. The height of this triangle, or

$$F = \frac{c}{\cotan A + \cotan B}.$$

Draw Fig. 370, with holes of equal diameters to be bored tangent to the adjacent sides of the three angles. Draw lines between the centers of the holes. Then the interior triangle is similar to the exterior triangle,

and the corresponding angles are equal. From these three figures we have the following simple equations:

$$G = \cotan E \times R,$$
$$H = \cotan D \times R,$$
$$J = c - (G + H),$$
$$L = \frac{J}{\cotan A + \cotan B}$$
$$K = F - (L + R),$$
$$\angle P = 90° - \angle B,$$
$$M = \tan P \times L,$$
$$N = J - M.$$

It is good practice to check all mathematical computations. Complete a rectangle by drawing the dotted lines shown, and check F by using sines and cosines. Then compare the value with F in Fig. 369, and determine if $Q = c$.
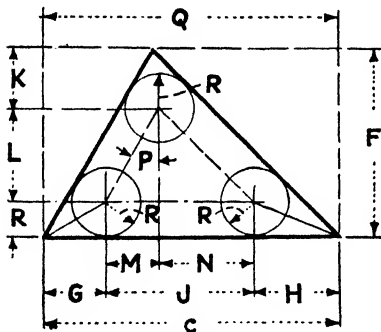
Fig. 370.
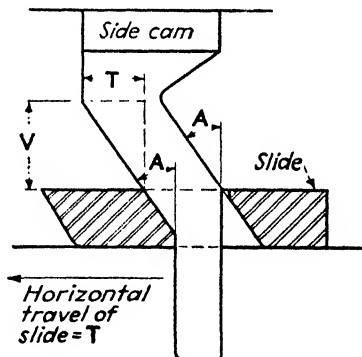
Fig. 371.—Illustrating the formulas for horizontal travel of slides which are operated by side cams.

Using Tables.—Tables are a great aid in tool engineering; they save much tedious figuring. The designer should supply himself with "American Machinists' Handbook" or similar data. Here will be found the natural trigonometric functions of angles; weights of sheet metals per square foot; circumferences and areas of circles, squares, cubes, roots, and reciprocals of numbers; and a large variety of other useful helps. He should have Barlow's or the equivalent tables of squares, cubes, roots, and reciprocals of numbers from unity up to 10,000. Tables of seven-place Briggs or common logarithms of numbers from unity up to 10,000 are useful for checking purposes. These tables include the logarithms of the natural trigonometric func-

tions of angles advancing by 10 sec. of arc. They also give the arc lengths for a radius of 1, which include every degree, minute, and second.

Determining Horizontal Travel for Cam Slides.—The best angle for operating slides that are actuated by side cams attached on the punch holder is 35 deg. for angle A in Fig. 371. Let T = horizontal travel of the slide and V = vertical descent of the side cam. Then $T = \tan A \times V$, and $V = T/\tan A$. When $A = 35$ deg., $T = 0.7V$, and $V = T/0.7$. However, 35 deg. cannot always be chosen for angle A. There may be conditions where the press stroke is short in proportion to the required slide travel, and angle A may be 45 deg. or more.

SHORT-CUT SOLUTIONS FOR DEVELOPING SHELL BLANKS

Developing blanks has been a much discussed subject. It has been rightfully ruled out of most mechanical publications by the editors. All that can be said about blank developments has been written and illustrated a hundred times. Apparently no additional information or improved methods for developing shell blanks have been discovered in about fifty years. Nevertheless it is an important subject and one that cannot be slighted in this discussion on the press-working of metals.

The "short-cut solutions," mentioned above, refer to recent applications in the use of the tables for blank diameters of cylindrical shells. They also refer to additional uses for the theorems of Pappus. Notwithstanding the fact that the tabulated blank diameters for cylindrical shells are for square-cornered shells and that these cannot be practically drawn without corner fractures, it is quite clear that there would be many uses for a reliable formula that could convert different shapes of shells into the terms of the blank diameters given in the tables. These conversion formulas have been discovered and have not only proved their worth by avoiding tedious computations but have also greatly enhanced the value of the tables.

Converting Round-cornered Shells into Square-cornered Shells.—The standard formula for the blank diameter of square-cornered cylindrical shells is $D = \sqrt{d^2 + 4dh}$. A very close approximation for the blank diameter of a round-cornered cylindrical shell, as at A, Fig. 372, is effected by laying out a square-cornered shell B, with the diameters d of both shells equal but with $h = H - 0.43r$; then the blank diameter for either of the shells is $D = \sqrt{d^2 + 4dh}$.

Another case is for a cylindrical shell having a hemispherical bottom, as shown at A in Fig. 373. The usual formula for the blank

diameter in this case is $D = 1.414\sqrt{d^2 + 2dh}$. However, by redimensioning the shell as shown at B and by laying out a square-cornered shell as at C, with the diameters d all equal but at C, with $h = H - r/2$, then the blank diameter for any one of the three shells is $D = \sqrt{d^2 + 4dh}$, using h as found in C.

The advantage in substituting the standard formula

$$D = \sqrt{d^2 + 4dh}$$

wherever possible is that all the tables giving approximate blank diameters for cylindrical shells are based on this formula. In finding the blank diameters for shells, such as those shown at A in Figs. 372 and 373, the diameters can often be taken directly from the tables, thus eliminating long computations.
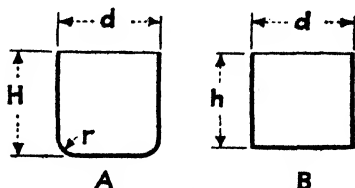
Fig. 372.—Illustrating a formula for converting a round-cornered shell into a square-cornered shell.
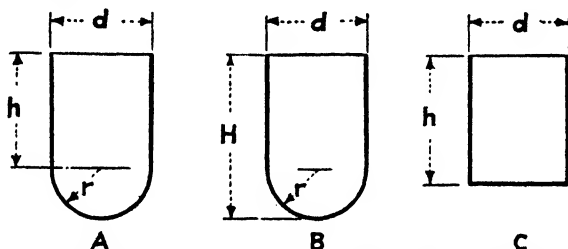
Fig. 373.—Illustrating a formula for converting a shell having a hemispherical bottom into a square-cornered shell.
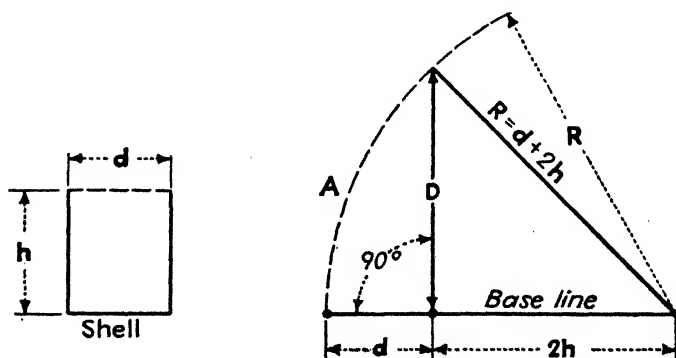
Fig. 374.—A diagrammatic layout of the blank for the shell shown at the left.

Diagrams for Shell Blanks.—This method for developing blanks is probably simplest because it eliminates mathematics. Blanks for any standard shapes of shells can be solved by a diagram.

The standard formula $D = \sqrt{d^2 + 4dh}$ can easily be proved by a diagram.

On any horizontal base line (Fig. 374) lay out distances d and $2h$, and use them for a radius in describing the arc A. Erect a perpendicular line D at the point between d and $2h$, cutting the arc as shown. Then distance D is the shell-blank diameter.

Proof:

$$D^2 = (d + 2h)^2 - 4h^2,$$
$$D^2 = d^2 + 4dh + \cancel{4h^2} - \cancel{4h^2},$$
$$D^2 = d^2 + 4dh,$$
$$D = \sqrt{d^2 + 4dh}.$$

For the blank development of the shell shown in Fig. 375, proceed as follows: Make a diagram of the type shown in the figure. Draw
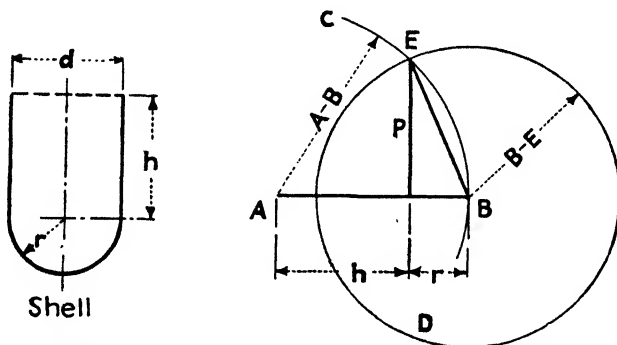
FIG. 375.—A diagrammatic layout of the blank for the shell shown at the left.

the horizontal line A-B, equal in length to $h + r$. Using point A as a center and with A-B for the radius, describe the indefinite arc B-C. From A lay out distance h on line A-B, and at this point erect the perpendicular line P, touching arc B-C at E. With point B as the center and B-E for a radius, describe circle D. Then circle D represents the diameter of the blank.

Computing Cylindrical Areas by Theorems of Pappus.*—The area of a rectangle is its length multiplied by its width, or $C \times H$, as shown at A in Fig. 376. If this rectangle is wrapped around a cylindrical tube, having a circumference C and height H, as shown at B, the external area of the tube is also $C \times H$. Since circumference C is πD, the outside area of a tube is its diameter multiplied by π times its height, or $A = \pi DH$.

* Pappus was a Greek mathematician and writer who lived at Alexandria in the third century A.D.

These simple formulas are important in understanding and applying the theorems of Pappus. The use of these theorems is quite simple. By their use we can accurately compute the area generated by any line in circular revolution parallel to an axis.

Applying the theorem in *B*, the length of vertical line *H* in revolution about vertical axis *X-X* multiplied by the circumference traced by the point of horizontal radius *R* is the generated area of the cylindrical surface thus produced, or $A = 2\pi R H$.

The theorem of Pappus, or the centrobaric method, is useful in computing the areas of cylindrically drawn shells, and, having the area, the corresponding blank diameter $D = 1.128\sqrt{\text{area}}$. These compu-
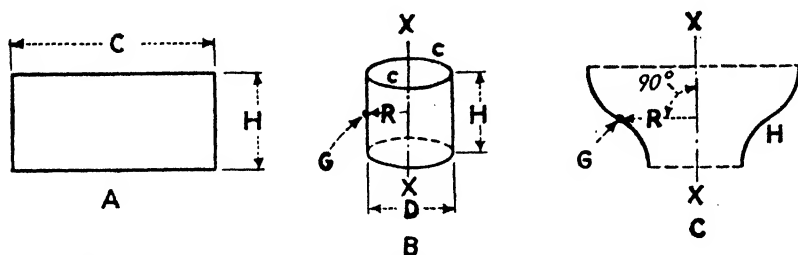
Fɪɢ. 376.—Illustrating a solution for the areas generated by revolving any line, such as line *H*, about a parallel axis *X-X* using radius *R*, which touches the center of gravity of line *H* at *G*.

tations can be made from prints that give only the finished shell dimensions.

This theorem is based on the principle that if any given line, as *H* in Fig. 376, is revolved in a plane parallel to an axis *X-X*, by a radius drawn at right angles from the axis and touching the center of gravity of the line, the line will generate, in one revolution, an area equal to its length multiplied by the circumference traced by the center of gravity.

At *C* in Fig. 376, if line *H* is revolved about vertical axis *X-X*, by horizontal radius *R*, which touches point *G* at the center of gravity of the length of line *H*, then in one revolution line *H* will generate a surface whose area is equal to $2\pi R H$. Since this formula and the one for the surface of a plain cylinder are the same, we must conclude that computing areas with the theorem of Pappus is very simple, and its only extra requirement is that the centers of gravities of the lines be found.

Graphical Determination of Blank Diameters for Any Cylindrical Shell.—This principle for determining circular blank diameters is simply a graph of the theorem of Pappus. Figures 377 and 378 are

examples in which the trial blank is developed for the circular shell shown above the graph.

Make an accurate contour layout of the shell section along its center line (Fig. 377). Divide it into sections A, B, C, D, E, and F. Drop lines from the center of gravity of each section a, b, c, d, e, and f. Draw the vertical line X-X, at one side as shown in Fig. 378, and space off the developed lengths of each section A, B, C, etc., using dividers. Draw lines to the ends of each section from any point P, and number them as shown. Draw a parallel to line 1, Fig. 378, between lines a and b in Fig. 377; also a parallel to line 2, between lines b and c (from
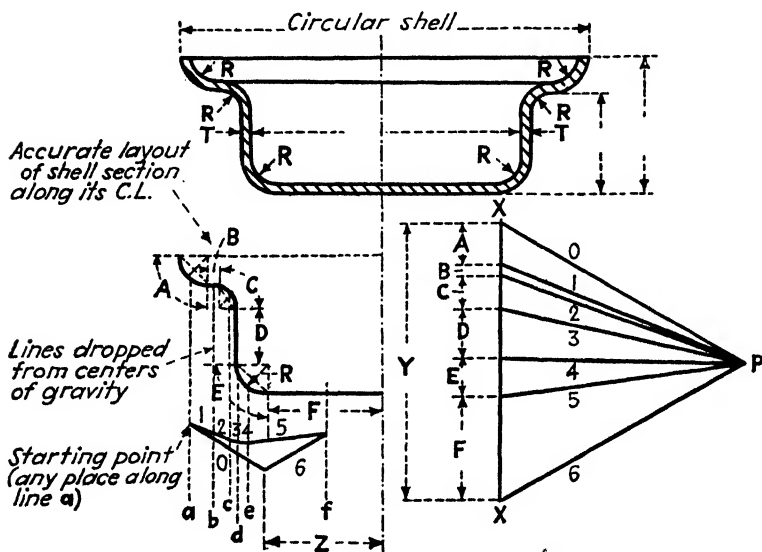
FIG. 377.   FIG. 378.

FIGS. 377 and 378.—Showing the graphical method for determining trial blank diameters for circular shells.

the intersection of lines 1 and b); a parallel to lines 3 between lines c and d, etc.; and finally a parallel to line 6, drawn to its intersection with line O, Fig. 377, which is parallel to line O, Fig. 378. Scale distances Y, Fig. 378, and Z, Fig. 377, to the nearest half sixty-fourth of an inch; multiply them together; then multiply by 8 (a constant); and extract the square root. The result will be the trial blank diameter. When R is less than $2T$, the center of gravity may be assumed to be halfway along the arc.

Figure 379 represents a dimensioned circular shell, taken from practice, in which the trial blank diameter is $4\frac{5}{8}$ in., determined by the graphical method.

Calculating Blank Diameters for Any Circular Shell.—When more accurate blank diameters than those developed by graphs are wanted,
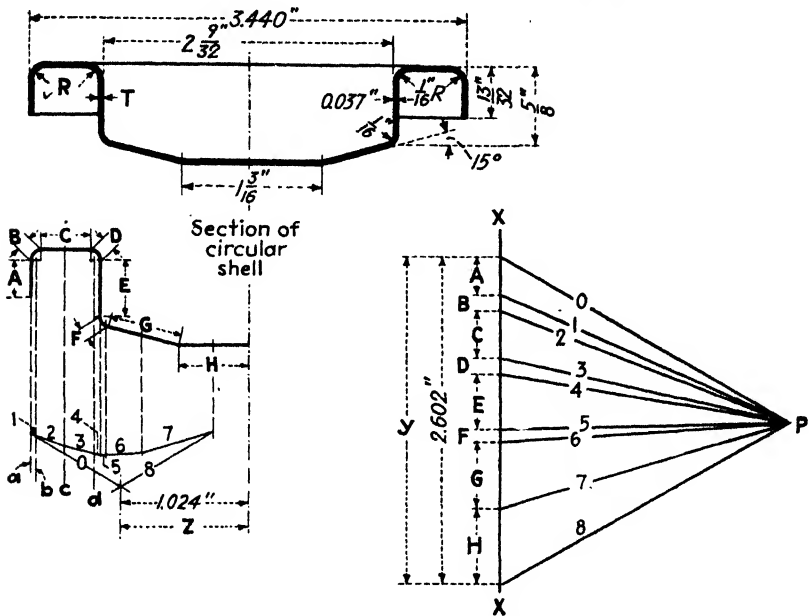
FIG. 379.—Developing the blank diameter for a circular shell by the graphical method
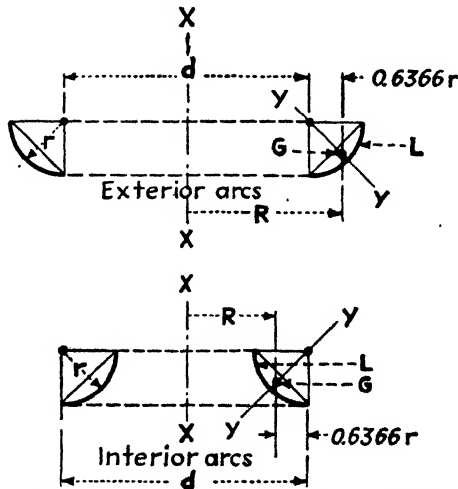
FIG. 380.—Calculating the surface areas of circular arc quadrants.

the following method gives the mathematical calculations. Figure 380 shows how the areas of exterior and interior circular arc quadrants

are computed. In the following formulas, A represents the areas of arcs, G the centers of gravity of arcs, and L the length of arcs.

For exterior circular arc quadrants, the center of gravity G is located on line y-y, which bisects the arc, and at a point $0.6366r$ from
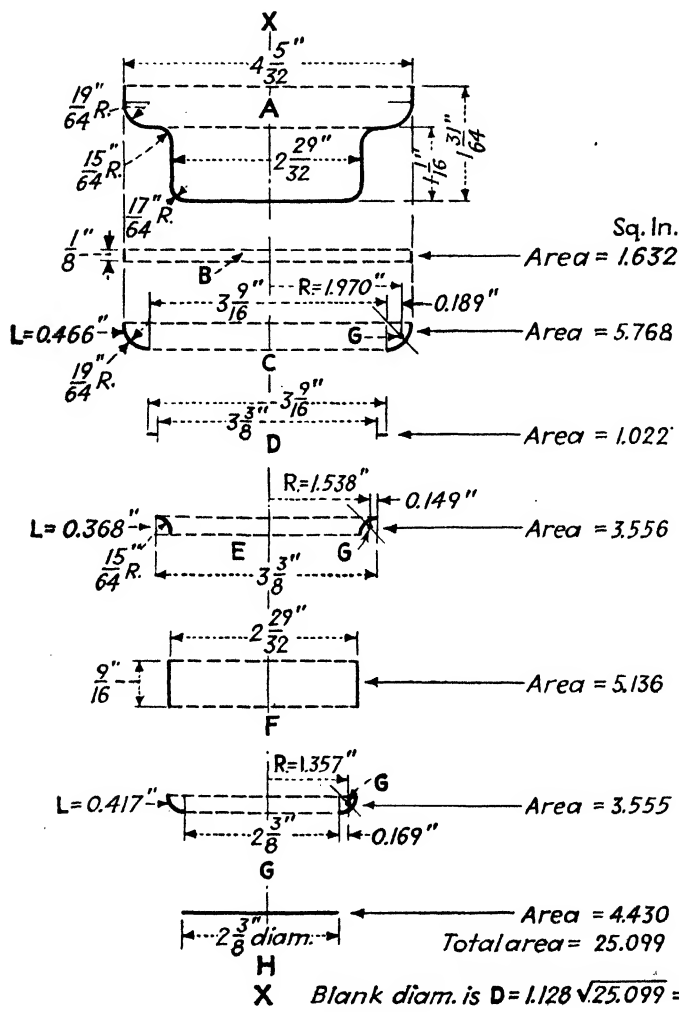
Fig. 381.

the center of r. $R = \dfrac{d}{2} + 0.6366r$, and $A = 6.283RL$. For interior circular-arc quadrants, $R = \dfrac{d}{2} - 0.6366r$, and $A = 6.283RL$.

To find the blank diameter for the diametrical cross section of a shell layout made along the center line of its wall, as illustrated in Fig. 381 at A, proceed as follows:

Separate the shell into its component cross-sectional parts, as at B, C, D, E, F, G, and H, about the center line X-X. At B and F apply the formula for areas of cylinders; at C and G, the formula for exterior quadrants; at E, the formula for interior quadrants; at D, the formula for the area of a ring; and at H, the formula for the area of a circle. Total the areas, and extract the square root; multiply the root by 1.128; and we have 5.651, or $5\frac{21}{32}$, in., for the blank diameter. As mentioned previously, tables can be used for much of this work, such as the lengths of arcs and the diameters and areas of circles.

Deriving Short Cuts for Calculating Circular Blank Diameters.— Since the area A of any circle is $A = 0.7854D^2$, it follows by algebraic transposition that $D = \sqrt{A/0.7854}$, or, stated in a more usable form, $D = 1.128\sqrt{A}$. This is the derivation for the formula used in determining the foregoing blank diameters from the shell areas. However, we can change the form of $D = 1.128\sqrt{A}$ again, without altering its value, and thus greatly shorten computations for shell-blank diameters. If the area of any section of a cylindrical shell is $d\pi h$, where h is its height and d the diameter, then:

$$1.128\sqrt{A} = 1.128\sqrt{d\pi h},$$

and introducing 1.128 under the radical sign by squaring and multiplying it by π, we have $\sqrt{4dh}$, or $2\sqrt{dh}$. This short-cut formula indicates that instead of laboriously computing the areas of all the component parts of shells, it is necessary only to multiply the distance, or diameter, between the centers of gravity by the length of the contour line involved in the sections. Then total the products of all the sections; extract the square root; and multiply by 2. This will give the blank diameter for the shell.

Applying this formula $2\sqrt{dh}$ for the shell considered under Fig. 381, we have the following shorter method:

Section B = 0.5195
Section C = 1.8360
Section D = 0.3261
Section E = 1.1320
Section F = 1.6346
Section G = 1.1317
Section H = 1.4090
Total = 7.9889

The square root of 7.9889 multiplied by $2 = 5.652$, or $5^{21}\!\!/_{32}$, in., for the blank diameter.

BLANK DEVELOPMENTS FOR SQUARE AND RECTANGULAR SHELLS

Introduction.—In the production of drawn work, the die for drawing the finished shell is always made first. This is a precautionary measure, because the condition of the work that comes from this die indicates whether the piece can be successfully drawn in one operation or if one or more preforming or drawing operations must be added.

If the work from this die shows that a single drawing operation is feasible, then different sizes and shapes of experimental blanks are made and drawn until the correct area and contour for the blank are discovered. Thus, for a sequence of drawing dies, the blanking die is the last tool made, although it must necessarily be the first one used when the manufacture of the shells begins.

On the other hand, if additional draws are found to be necessary, this need is indicated by the appearance and position of cracks, ruptures, thinned walls, or other apparent faults in the work. These discrepancies are usually of a nature that may suggest the approximate sizes and shapes for the necessary intermediate shells that will lead up to the final production of a perfect piece of work.

Laying Out a Blank for Rectangular Shells.—In Fig. 382 at A is a line drawing for a rectangularly drawn shell for which an approximate blank development is required. The outlines of this piece are drawn and dimensioned along the center lines of the walls of the finished shell. Dimension F should include $\frac{1}{8}$ in. for trimming the shell of the waved edges around its top. This operation can be done by "pinch trimming" at the finish of the draw in the drawing die. However, if a perfectly square edge is desirable, trimming is done in a separate operation, using one of the methods explained in Chap. XV. In drawing square and rectangular shells, the metal is forced into plastic flow only around the four corners; the sides are simply plain bending operations.

Lay out rectangle B, in which $W = C + 2F +$ twice the length of the arc described by radius r, and lay out $L = E + 2F +$ twice the length of the same arc. Lay out the plan view of shell A, symmetrically positioned within rectangle B. Determine the blank diameter D of a cylindrical shell having a body radius of r, height F, and a hemispherical bottom r, as described under Fig. 373. Scribe the radius $D/2$ as shown. This radius is one-half the blank diameter just developed. Draw the lines G-G, at 45 deg. as indicated, and connect them with the sides of rectangle B, using the curved lines H. H can be a radius of about $2r$.

This development will serve all the purposes of a trial blank.   It will be sufficiently accurate for estimating the shearing width and blanking centers for the cost of material from which to order the die steels and for designing the blanking die.

After the first trial blank has been drawn in the die, it may be necessary for the toolmaker to change the outline of *H*, or other minor outlines of the blank, in order to obtain an even trim of scrap around the top of the shell.
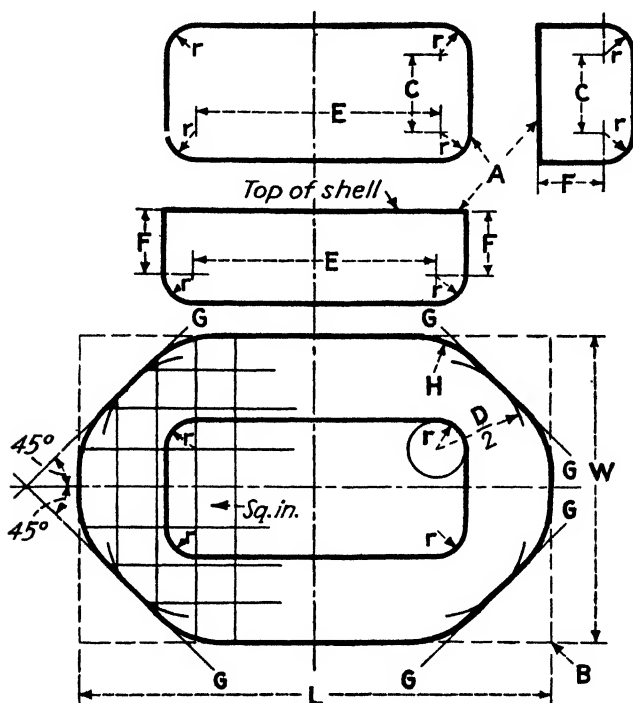
Fig. 382.—One method for laying out an approximate blank for a rectangular shell.

For checking blanks of this character, compute the area of the finished shell, divide the blank into square inches as indicated, and then compare the areas.   However, this procedure will not determine a blank contour of sufficient accuracy for evenly trimming the top. The shell will draw up too high at some places, usually at one or more of the corners, and it will be too low at other places.   These faults may be due to other causes than using an incorrect blank.   Improper lubrication, insufficient space between the punch and die, the entering radius into the die cavity too small, variation in material thickness, and the wrong temper of material are some of the conditions encountered.

Laying Out Blanks for Near-square Shells.—"Near-square shells" are specified because they are more difficult to determine correct blanks for, than are ordinary square shells. The reason for this is as follows. When a near-square shell has a depth of about its width, and the system for laying out a rectangular shell is tried, the blank development comes to a point at its ends. In other words, there will be insufficient metal available for drawing up the ends of the box. The same difficulty is found in laying out blanks for rectangular shells, when the width of the box is less than about one-third its length and the depth is greater than the width.

Those who have had the actual experience in developing blanks for square and rectangular shells and who have followed up results in the
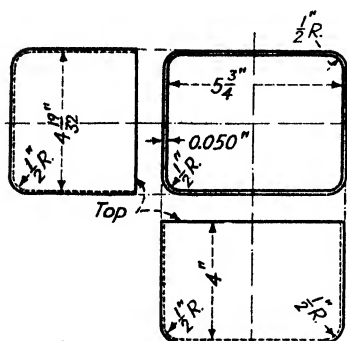
Fig. 383.—A rectangularly drawn steel shell.
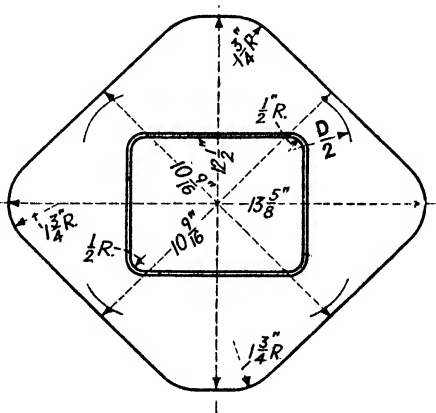
Fig. 384.—Trial blank development for the box shell shown in Fig. 383.

shop know that practically all theoretical rules in regard to limits on the depths of draws can be discarded. These types of shells can be drawn much deeper in one operation than is generally thought. For example, they tell us that the depth limit for drawing these shells is six times the corner radius. However, in Fig. 383 is a sketch for a shell, taken from recent practice, in which the depth is more than eight times the corner radius, after we add ⅛ in. to the height for trimming. Furthermore, this box was successfully drawn in one operation from 0.050-in. deep-drawing steel. Without any doubt whatever this work could have been drawn to depths of ten or more times its corner radius without showing signs of serious thinning, cracks, or ruptures.

In Fig. 384 the layout for the rectangle of this blank, around the plan view of the shell, is about ½ in. greater, in developed width and

length, than the rule given for laying out blanks for rectangular shells. Therefore, the straight-side outlines of the blank are ¼ in. further out than $D/2$, as shown in the figure.

.The area of this blank was determined and compared with the computed area of the finished shell. The two areas were found practically the same. When this blank was tried out in the drawing die, it was found to be very close to the correct size. The final blank contour as developed by the toolmaker is shown in Fig. 385. Practically the only changes made were along the edges of the blank. These were thought necessary in order to provide metal at some of the low
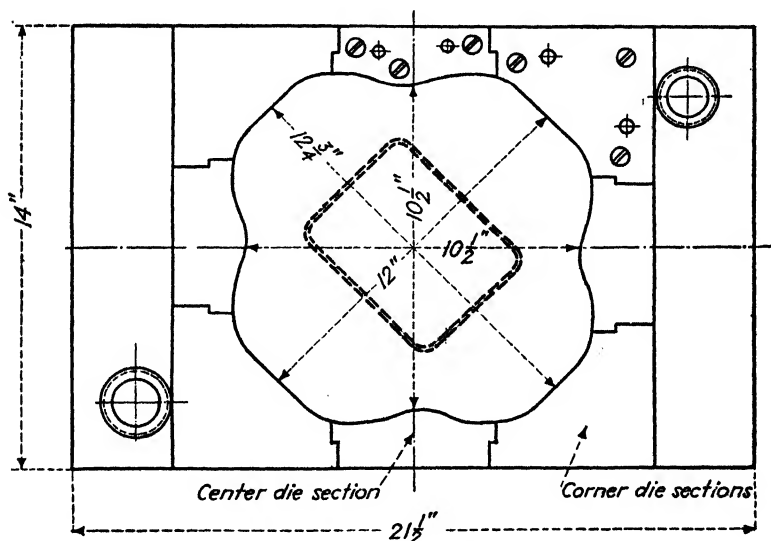
Fig. 385.—Face of punch holder, showing the blanking die sections, and the correct blank outline.

places and to remove metal at the high places, so that an even trim of scrap was obtained around the top of the box.

Attention should be directed here to the design of the die sections on the punch holder of the blanking die. In Fig. 385 it will be noticed that the four center sections are notched so as to interlock into the corner sections. Of course, the purpose for this type of die-section design is to take the thrust of the cut without spreading.

It is not often necessary to make more than a single draw for steel shells if the material thicknesses exceed about 0.050 in. gage. If wrinkles occur when the metal is drawn over the die radius at the corners, they can be avoided by using a larger blank. Use a blank

large enough so that a generous width of shell flange remains under the blank holder after the shell has been drawn.

In drawing deep and tapered aluminum pans, two operations are frequently necessary. In Chapter XXII will be found several layouts for more than one drawing operation of rectangular work.

Drawing, Stretching, and Forming Bowl Shapes.—Figure 386 illustrates the six drawing operations necessary in producing the sheet-metal bowl shown finished in the sixth operation. The bowl is produced by a series of drawing and redrawing, stretching, and, in the last operation, drawing and forming. Each of the intermediate operations is designed to lead up to the production of the finished piece. It will
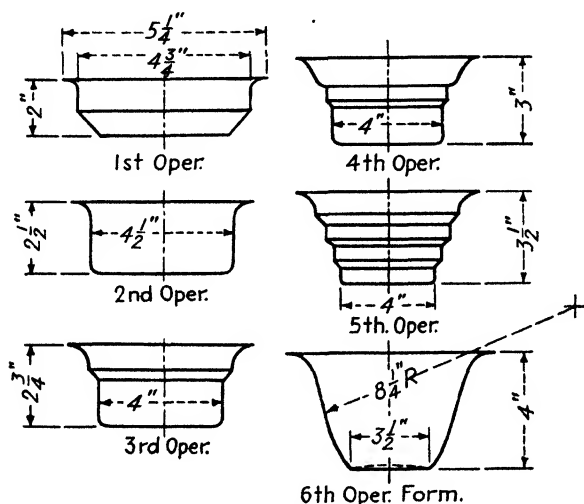
FIG. 386.—Illustrating the drawing and stretching of a bowl-shaped shell in six operations.

be observed that the third, fourth, and fifth operations are made up by adding steps that roughly give the wall of the shell a conical outline. In the final operation the steps are stretched and drawn out to the contour of an $8\frac{1}{4}$ in. radius.

In the first operation the shell area is approximately 55 sq. in., whereas the finished piece has an area of nearly 60 sq. in. This small increase in area indicates that the metal has been slightly thinned. It does not, however, show any appreciable decrease in wall thickness, by micrometer readings, except in the wall thickness around near the bottom of the bowl.

When computing blank areas and diameters for this type of work, the area of the finished shell is used. A flange is provided around the tops of the shells of a size that is useful for blank-holding purposes

while the stretches are being made. These operations are produced in a double-action drawing press.

The percentages of reductions for the shell diameters are 5½ per cent between the first and second operations, 11 per cent between the second and third, and 12½ per cent between the fifth and sixth. Percentages for shell reductions are computed as follows. If D is the larger diameter, and C the smaller, then $\dfrac{D - C}{D}$ = the percentage of reduction.

Developing Blanks for Odd Shapes of Shells.—Blank developments for cross-sectional shapes of shells that may be oval, parabolic, elliptical, etc., can be approximately determined by making simple graphical layouts. Figure 387 represents the outlines of a shell whose cross section is of elliptical shape. The outlines shown are the center lines of the shell walls. Dimension F includes about ⅛ in. for an even trim around the top of the shell.

These types of layouts are somewhat similar to those made for blank developments of rectangular shells. Figure 388 shows the shell opened up on a plane surface. Length $L = E + 2F$ + twice the length of the arc described by radius r. Width W is developed in a similar

FIG. 387.—The outlines of an elliptically shaped shell.

manner. Lay out the plan view of the finished shell, represented by the ellipse A, and position it symmetrically within width W and length L.

It is now apparent that if we cut out regular spaces B, C, etc., along the peripheries of A and N, making a series of spokes in which the total widths of D are equal to periphery A, we have a blank which will form the shell. In other words, if we used this layout of spokes in the drawing die, the resulting work would be a formed-up shell whose size, shape, and depth would be correct. However, there would be a series of vertically cut strips around the shell body, as indicated in Fig. 387.

Obviously, the next step is to scribe the elliptically shaped dotted line M, such that the areas of surfaces G are equal to those of H. The

dotted line represents the approximate shape and size of the desired blank.

It should be pointed out here that the first four spokes, at the left in Fig. 388, are focused toward point f, whereas all the remaining spokes are focused toward the center of radius K. Since radius K is $1\frac{5}{8}$ times longer than the length of radius J, it follows that spaces B must be made $1\frac{5}{8}$ times greater than those of C.
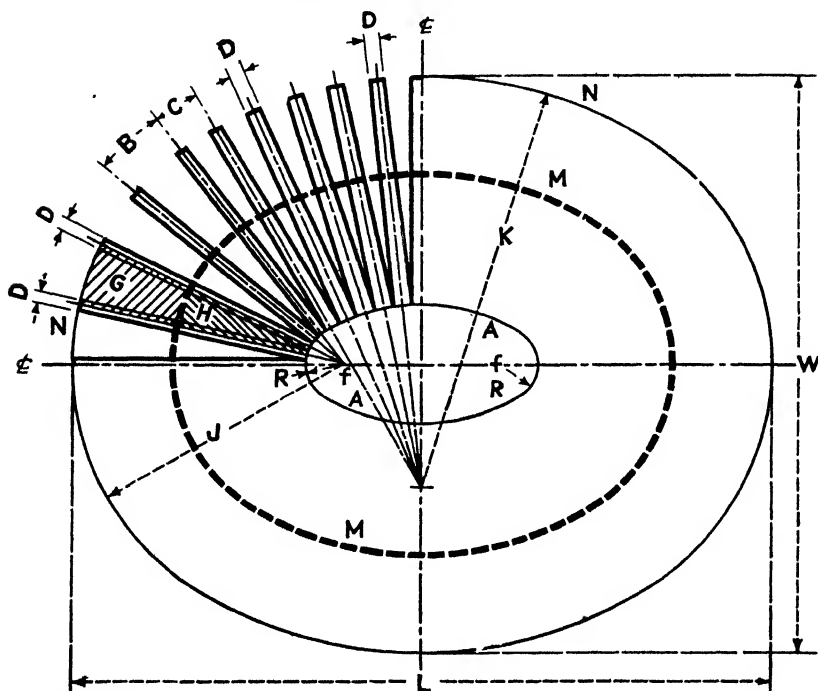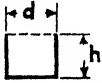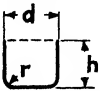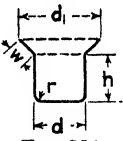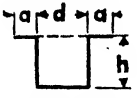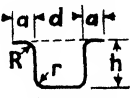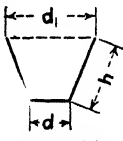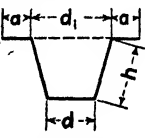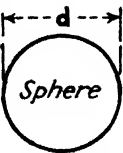
Fig. 388.—Blank development for the elliptically shaped shell shown in Fig. 387. The dotted line M-M represents the approximate blank outline.

Obviously, the principle involved here is that when the developed blank is placed in the drawing die and the punch descends upon it and starts to draw it into the die cavity, a plastic flow is immediately set up above the bottom of the shell. The result is that spaces H "flow" into spaces G, and thus the desired shell is drawn up to size.

Blank Diameters for Common Shapes of Cylindrical Shells.— Figures 389 to 407, inclusive, include 19 formulas which will be found of considerable value for quickly computing the diameters of blanks for standard shapes of circular shells. The formulas have been reduced to their lowest terms.
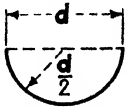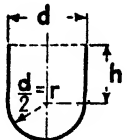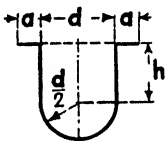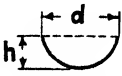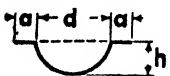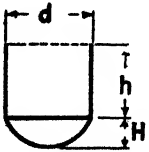
Areas for Common Shapes of Cylindrical Shells.—Figures 408 to 414, inclusive, give short-cut formulas for finding the areas for seven

Formulas for Blank Diameters of Cylindrical Shells

Fig. 389.	$D = \sqrt{d^2 + 4dh}$ for square corners
Fig. 390.	$D = \sqrt{d^2 + 4d(h - 0.43r)}$ for round corners
Fig. 391.	$D = \sqrt{d^2 + 4d(h - 0.43r) + 2w(d_1 + d)}$
Fig. 392.	$D = \sqrt{(d + 2a)^2 + 4dh}$
Fig. 393.	$D = \sqrt{(d + 2a)^2 + 4d[h - (0.43r + 0.43R)]}$
Fig. 394.	$D = \sqrt{2h(d_1 + d) + d^2}$
Fig. 395.	$D = \sqrt{2h(d_1 + d) + d^2 + [(d_1 + 2a)^2 - d_1^2]}$
Sphere Fig. 396.	$D = 1.128\sqrt{\pi d^2} = 2d$
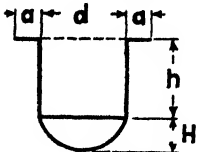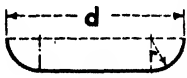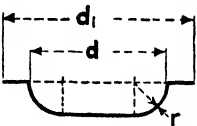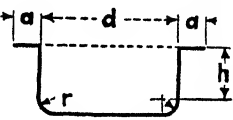
The area of a blank is $A = \dfrac{D^2}{1.273}$

Formulas for Blank Diameters of Cylindrical Shells

Hemisphere FIG. 397.	$D = \sqrt{2d^2} = 1.414d$
FIG. 398.	$D = \sqrt{d^2 + 4d(h + 0.5r)}$
FIG. 399.	$D = \sqrt{(d + 2a)^2 + d^2}$
FIG. 400.	$D = \sqrt{(d + 2a)^2 + d^2 + 4dh}$
FIG. 401.	$D = \sqrt{d^2 + 4h^2}$
FIG. 402.	$D = \sqrt{(d + 2a)^2 + 4h^2}$
FIG. 403.	$D = \sqrt{d^2 + 4(H^2 + dh)}$
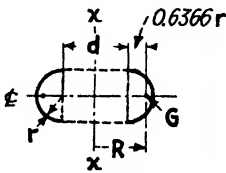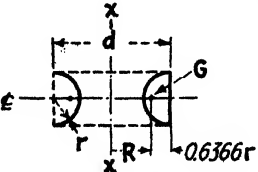
The area of a blank is $A = \dfrac{D^2}{1.273}$

Formulas for Blank Diameters of Cylindrical Shells

 FIG. 404.	$D = \sqrt{(d + 2a)^2 + 4(H^2 + dh)}$
 FIG. 405.	$D = \sqrt{d^2 + 2.28rd - 0.56r^2}$
 FIG. 406.	$D = \sqrt{d_1^2 + 2.28rd - 0.56r^2}$
 FIG. 407.	$D = \sqrt{(d + 2a)^2 + 4d(0.57r + h) - 0.56r^2}$

The area of a blank is $A = \dfrac{D^2}{1.273}$

Formulas for Areas of Shell Parts

 FIG. 408.	*Exterior Semicircular Arcs, when G is the Center of Gravity of the Arcs, and l is the Length of Arc,* $R = \dfrac{d}{2} + 0.6366r \qquad A = 6.283Rl$
 FIG. 409.	*Interior Semicircular Arcs* $R = \dfrac{d}{2} - 0.6366r \qquad A = 6.283Rl$

l = length of arc   Blank diameter $D = 1.128\sqrt{A}$

Formulas for Areas of Shell Parts
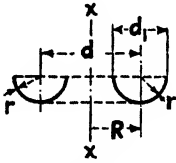
FIG. 410.

Horizontal Semicircular Arcs
One Half of a Wiring Ring

$$R = \frac{d}{2} \qquad A = 6.283Rl$$

$$\text{Also } A = \frac{9.87dd_1}{2}$$
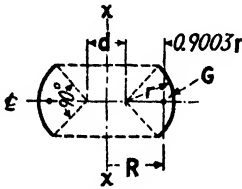
FIG. 411.

Vertical Circular Arc Quadrants

$$R = \frac{d}{2} + 0.9003r \qquad A = 6.283Rl$$
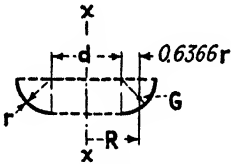
FIG. 412.

Exterior Circular Arc Quadrants
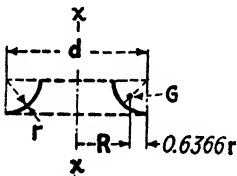
$$R = \frac{d}{2} + 0.6366r \qquad A = 6.283Rl$$

FIG. 413.

Interior Circular Arc Quadrants

$$R = \frac{d}{2} - 0.6366r \qquad A = 6.283Rl$$
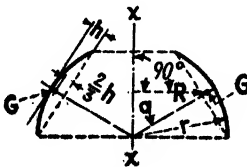
FIG. 414.

Circular Arcs Less Than Quadrants, and Symmetrically Positioned at Any Angle to Axis x-x

$$R = \left(r - \frac{h}{3}\right) \cos a \qquad A = 6.283Rl$$

l = length of arc   Blank diameter $D = 1.128\sqrt{A}$

standard shapes of circular sections. The sections given are those which arise for solution most frequently as component parts of circular shells.
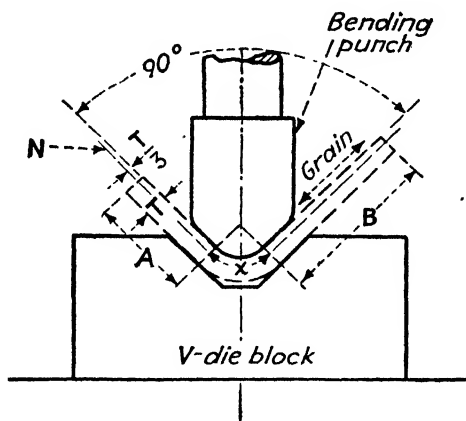
FIG. 415.—A typical V-block bending die.

Tables for Lengths of Right-angle Bends.—In bending mild-tempered sheet metals in V-block dies, the neutral bending line N is theoretically located at one-third of the material thickness from inside the bends when the bends are made across the grain (Fig. 415). Table II gives the lengths of arc X when bending 90-deg. angles in the commonly used gage thicknesses. The developed length of the piece is
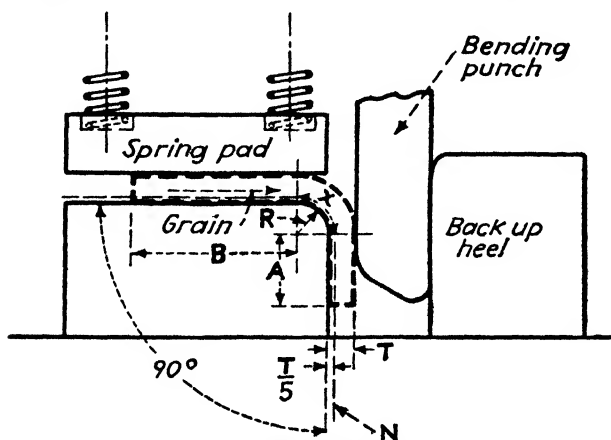
FIG. 416.—A typical spring-pad bending die.

$A + X + B$. For the arc lengths of other angles than 90 deg., length X is proportional to the number of degrees in the angle. For example: in a 1-deg. bend, length X is one-ninetieth of the tabulated figures.

TABLE II.—LENGTHS OF ARCS FOR 90-DEG. BENDS ACROSS THE GRAIN IN V-DIES

(Formula $(T/3 + R) \times 1.5708$)

T = thickness of metal, in.

Radius R	0.010	0.015	0.020	0.025	0.031	0.037	0.050	0.062	0.078	0.093	0.109	0.125	0.140	0.156	0.187	0.250
0	0.0052	0.0079	0.0105	0.0131	0.0162	0.0193	0.0262	0.0325	0.0408	0.0487	0.0570	0.0655	0.0734	0.0817	0.0979	0.1308
0.005	0.0130	0.0157	0.0184	0.0209	0.0240	0.0272	0.0340	0.0404	0.0487	0.0565	0.0649	0.0733	0.0812	0.0895	0.1057	0.1387
0.010	0.0209	0.0236	0.0262	0.0287	0.0319	0.0350	0.0419	0.0482	0.0565	0.0644	0.0727	0.0812	0.0891	0.0974	0.1136	0.1466
0.015	0.0287	0.0314	0.0341	0.0366	0.0397	0.0429	0.0498	0.0561	0.0644	0.0723	0.0806	0.0891	0.0970	0.1052	0.1214	0.1544
0.020	0.0366	0.0393	0.0419	0.0445	0.0476	0.0507	0.0576	0.0639	0.0723	0.0801	0.0884	0.0969	0.1048	0.1131	0.1293	0.1623
1/32	0.0542	0.0569	0.0595	0.0620	0.0652	0.0683	0.0752	0.0815	0.0898	0.0977	0.1060	0.1145	0.1224	0.1307	0.1469	0.1799
1/16	0.1034	0.1060	0.1087	0.1112	0.1144	0.1175	0.1244	0.1307	0.1390	0.1469	0.1552	0.1637	0.1715	0.1799	0.1960	0.2290
3/32	0.1524	0.1550	0.1577	0.1602	0.1634	0.1665	0.1734	0.1797	0.1880	0.1959	0.2042	0.2126	0.2205	0.2289	0.2450	0.2780
1/8	0.2015	0.2042	0.2069	0.2094	0.2125	0.2157	0.2226	0.2289	0.2372	0.2450	0.2534	0.2618	0.2697	0.2780	0.2942	0.3272
5/32	0.2505	0.2532	0.2559	0.2584	0.2615	0.2647	0.2716	0.2779	0.2862	0.2940	0.3024	0.3109	0.3187	0.3270	0.3432	0.3762
3/16	0.2997	0.3024	0.3050	0.3076	0.3107	0.3138	0.3208	0.3270	0.3354	0.3432	0.3515	0.3600	0.3679	0.3762	0.3924	0.4254
7/32	0.3487	0.3514	0.3540	0.3566	0.3597	0.3629	0.3698	0.3760	0.3844	0.3922	0.4006	0.4090	0.4169	0.4252	0.4414	0.4744
1/4	0.3979	0.4006	0.4032	0.4057	0.4089	0.4120	0.4189	0.4252	0.4335	0.4414	0.4497	0.4582	0.4661	0.4744	0.4906	0.5235
9/32	0.4469	0.4496	0.4522	0.4547	0.4579	0.4610	0.4679	0.4742	0.4825	0.4904	0.4987	0.5072	0.5151	0.5234	0.5396	0.5726
5/16	0.4961	0.4987	0.5014	0.5039	0.5071	0.5102	0.5171	0.5234	0.5317	0.5396	0.5479	0.5564	0.5642	0.5726	0.5887	0.6217
3/8	0.5942	0.5969	0.5996	0.6021	0.6052	0.6084	0.6153	0.6216	0.6299	0.6377	0.6461	0.6546	0.6624	0.6707	0.6869	0.7199
1/2	0.7906	0.7933	0.7959	0.7984	0.8016	0.8047	0.8116	0.8179	0.8262	0.8341	0.8424	0.8507	0.8588	0.8671	0.8833	0.9162

TABLE III.—LENGTHS OF ARCS FOR 90-DEG. BENDS ACROSS THE GRAIN IN SPRING-PAD BENDING DIES

(Formula $(T/5 + R) \times 1.5708$)

T = thickness of metal, in.

Radius R	0.010	0.015	0.020	0.025	0.031	0.037	0.050	0.062	0.078	0.093	0.109	0.125	0.140	0.156	0.187	0.250
0	0.0031	0.0047	0.0063	0.0079	0.0097	0.0116	0.0157	0.0195	0.0245	0.0292	0.0342	0.0393	0.0440	0.0490	0.0587	0.0785
0.005	0.0110	0.0126	0.0141	0.0157	0.0176	0.0195	0.0236	0.0273	0.0324	0.0371	0.0421	0.0471	0.0518	0.0569	0.0666	0.0864
0.010	0.0188	0.0204	0.0220	0.0236	0.0254	0.0273	0.0314	0.0352	0.0402	0.0449	0.0500	0.0550	0.0597	0.0647	0.0745	0.0942
0.015	0.0267	0.0283	0.0298	0.0314	0.0333	0.0352	0.0393	0.0430	0.0480	0.0528	0.0578	0.0628	0.0675	0.0726	0.0823	0.1021
0.020	0.0346	0.0361	0.0377	0.0393	0.0412	0.0430	0.0471	0.0509	0.0559	0.0606	0.0656	0.0707	0.0754	0.0804	0.0901	0.1100
⅟₃₂	0.0522	0.0537	0.0553	0.0569	0.0587	0.0606	0.0647	0.0685	0.0735	0.0782	0.0833	0.0883	0.0930	0.0980	0.1078	0.1275
⅟₁₆	0.1013	0.1029	0.1045	0.1060	0.1079	0.1098	0.1139	0.1177	0.1227	0.1274	0.1324	0.1374	0.1422	0.1472	0.1570	0.1767
³⁄₃₂	0.1503	0.1519	0.1535	0.1550	0.1570	0.1588	0.1629	0.1667	0.1717	0.1764	0.1814	0.1865	0.1912	0.1962	0.2059	0.2257
⅛	0.1995	0.2011	0.2026	0.2042	0.2061	0.2080	0.2121	0.2158	0.2209	0.2256	0.2306	0.2356	0.2403	0.2454	0.2551	0.2749
⁵⁄₃₂	0.2485	0.2501	0.2516	0.2532	0.2551	0.2570	0.2611	0.2648	0.2699	0.2746	0.2796	0.2846	0.2893	0.2944	0.3041	0.3239
³⁄₁₆	0.2977	0.2992	0.3008	0.3024	0.3043	0.3061	0.3102	0.3140	0.3190	0.3237	0.3288	0.3338	0.3385	0.3435	0.3533	0.3731
⁷⁄₃₂	0.3467	0.3482	0.3498	0.3514	0.3533	0.3551	0.3592	0.3630	0.3680	0.3727	0.3778	0.3828	0.3875	0.3925	0.4023	0.4221
¼	0.3958	0.3973	0.3990	0.4006	0.4024	0.4043	0.4084	0.4122	0.4172	0.4219	0.4269	0.4320	0.4367	0.4417	0.4514	0.4712
⁹⁄₃₂	0.4448	0.4464	0.4480	0.4496	0.4514	0.4533	0.4574	0.4612	0.4662	0.4709	0.4760	0.4810	0.4857	0.4907	0.5005	0.5202
⁵⁄₁₆	0.4940	0.4956	0.4972	0.4987	0.5006	0.5025	0.5066	0.5104	0.5154	0.5201	0.5251	0.5301	0.5349	0.5399	0.5496	0.5694
⅜	0.5922	0.5938	0.5953	0.5969	0.5988	0.6007	0.6048	0.6085	0.6136	0.6183	0.6233	0.6283	0.6330	0.6381	0.6478	0.6676
½	0.7885	0.7901	0.7917	0.7933	0.7951	0.7970	0.8011	0.8049	0.8099	0.8146	0.8196	0.8247	0.8294	0.8344	0.8441	0.8639

For hard, tempered materials and especially for steel, it is best to use Table III for developing precise lengths of blanks.

For the spring-pad types of bending dies, the operations are not so severe as in V bending, and the neutral bending line is located at one-fifth of the material thickness from inside the bends. This is also for bends made across the grain (Fig. 416). Table III gives the lengths for arcs X. For other angles, the lengths of arcs are proportional to the number of degrees in the angle, as stated above.

In both tables, all the lengths for radii R, given below the heavy stepped lines, are greater than twice the metal thicknesses and must therefore be used with caution in precision work. But for ordinary bends where no great accuracy is necessary, these radii can be used. When the radius of a bend exceeds twice the thickness to be bent, the neutral bending line is at the center of the material thickness. This is especially true for soft sheet brass and other ductile metals.

Diameter of a Circle Whose Center Is Inaccessible.—In Fig. 417
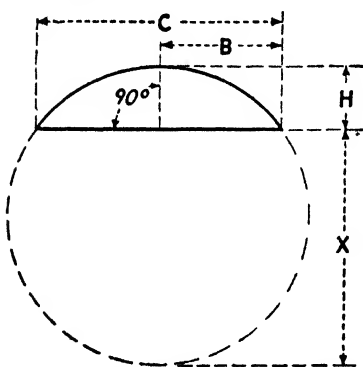
Fig. 417.—Given the arc of a circle, to find its unknown diameter.

lay out any convenient chord line C and height H of known dimensions. Lay out B as $\frac{1}{2}$ of C. Then by the first formula given under Fig. 354, $H/B = B/X$, $HX = B^2$, $X = B^2/H$ and $X + H$ is the unknown diameter.

Velocity Travel of a Press Crank Pin.—The circumferential travel, or velocity V, of a crank pin, circumference of a flywheel, or belt in feet per minute is $V = 0.262 \times D \times$ r.p.m., in which D is the diameter of the circle of revolution. This simple formula is also useful in finding the travel in feet per minute of drills, milling cutters, and work revolving in lathes, screw machines, etc. It is a convenient short-cut formula, as compared with $V = \pi \times D \times$ r.p.m./12, which is the standard formula from which it is taken.

Calculating Press Ram Descents.—In Fig. 418 all dimensions are in inches, and

A = angle of crank movement from zero;
B = angle of driving arm movement from zero;
T = "throw" or crank radius;
L = effective length of driving arm;
x = arc height of crank radius;
y = arc height of driving-arm radius;

then

$$x - y = \text{ram descent};$$
$$x = T\,(\text{versin }A);$$
$$y = L\,(\text{versin }B);$$
$$\sin B = \frac{\sin A \times T}{L};$$
$$\text{versin } A = 1.0000 - \cos A;$$
$$\text{versin } B = 1.0000 - \cos B.$$

In Fig. 419 all dimensions are in inches, and

$$x = \sin\,(A - 90°)T + T;$$
$$\sin B = \frac{\cos\,(A - 90°)T}{L}.$$

The remaining formulas for Fig. 419 are the same as those given under Fig. 418; that is, $y = L(\text{versin }B)$, and $x - y =$ ram descent.
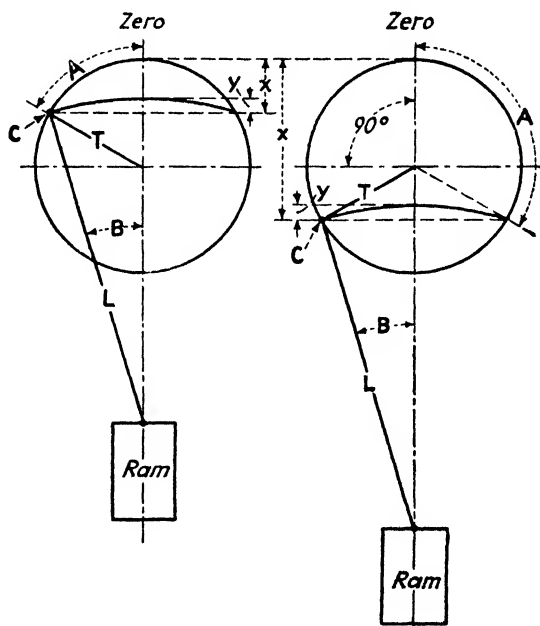
FIG. 418.—Illustrating the formula for calculating ram descent when crank C has advanced less than 90 deg.

FIG. 419.—Illustrating the formula for calculating ram descent when crank C has passed 90 deg.

When calculating the ram positions at points in its ascent, as at 248 deg. crank movement from zero, use the difference between 360

and 248 deg., or 112 deg., for A. This computation should always be made when the crank movement from zero is greater than 180 deg.

These formulas are useful for determining the position of the slide or piston head in crank-driven motors, relative to any assumed arc travel of the crank. They can be applied for solving the movements in any arm and pitman driving mechanism.

Position of Crank Pin at One-half the Ram Descent.—If $x - y =$ the ram descent, then a press ram (or punch) has descended one-half its full stroke when the height y of its driving-arm radius passes across the crankshaft center at F, Fig. 420.

In Fig. 420 consider $T = 1\frac{1}{4}$ in., $L = 6$ in., and that the driving-arm radius passes across F. By dividing the driving-arm angle B into two right triangles, as shown, and solving one of them, we find that angle $B = 11$ deg. 58 min. and that the angle of crank advance $A = 95$ deg. 59 min. Solving for x and y, $x = 1.380$ in., $y = 0.130$ in., and $x - y = 1\frac{1}{4}$ in., which is the ram descent and also one-half its full stroke.

It is usually near this point of high ram velocity that the punch contacts the blank when drawing fairly deep shells. Some manufacturers use coated metal,

Fig. 420.—Showing the position of crank-pin C at one-half the ram descent.

as coated blanks will take the thrust of the drawing punch more easily. The sheets are purchased tinned, copper plated, or lead coated.

Velocity Travel of Press Rams.—Referring again to Fig. 420 and assuming that the crankshaft is running 60 r.p.m. and solving E, which is one-half the chord of the driving-arm radius, we find that $E = 1.243$ in. The velocity travel V, in feet per minute, of the ram (or punch), at any position of crank pin C, is $V = 0.524 \times E \times$ r.p.m. In the case under consideration, $V = 0.524 \times 1.243 \times 60 = 39.08$ ft. per minute.

Computing Pulley and Gear Speeds.—It should always be kept in mind which wheel is the driver and which is to be driven. As illustrated in Fig. 421, the diameter of the driver times its r.p.m. equals the diameter of the driven times its r.p.m. What is the required pulley diameter on a motor shaft that revolves 1,800 r.p.m. that will cause a press flywheel, which is 30 in. in diameter, to revolve 120 r.p.m. when
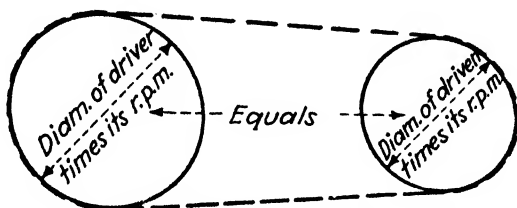
Fig. 421.—Showing the equality relationship between the driver and a driven pulley.

belted up? Using the foregoing formula, the required diameter D is:
$$D \times 1,800 = 30 \times 120. \quad D = \frac{30 \times 120}{1,800}, \text{ or 2 in.}$$

Gear ratios are similarly figured, pitch diameters being used instead of pulley diameters. If the pitch diameters are unknown, count the number of teeth in the gears; then the number of teeth in the driving gear times its r.p.m. equals the number of teeth in the driven times its r.p.m.

Proposed scrap strip
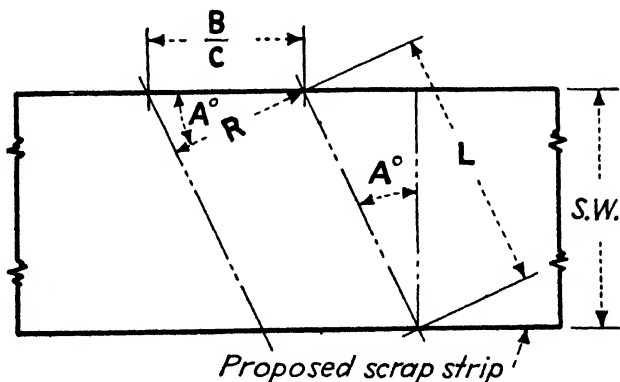
Fig. 422.

Mathematical Equations for Developing Scrap Strips.—Blanks that are positioned angularly across a scrap strip in single, double, or multiple rows can be accurately checked by using formulas. Any three of the following dimensions being known, the fourth can be determined by using the laws of simple proportion. In Fig. 422, the lettering represents the principal dimensions in any scrap strip.

A = angle of slant across the strip.

L = length of slant across the strip.

R = right-angle distance between slants.

B/C = blanking centers.

$S.W.$ = sheared width of strip.

By construction, angles A are equal.

$$\cos A = \frac{R}{B/C}, \quad \text{or} \quad \frac{S.W.}{L}. \qquad \text{Hence,} \; \frac{R}{B/C} = \frac{S.W.}{L},$$

$$B/C \times S.W. = R \times L.$$

$$B/C = \frac{R \times L}{S.W.}.$$

$$R = \frac{B/C \times S.W.}{L}.$$

$$L = \frac{B/C \times S.W.}{R}.$$

A Centralizing Device for Die Strips.—For centralizing and guiding a strip across the face of a die so that pierced holes or other openings
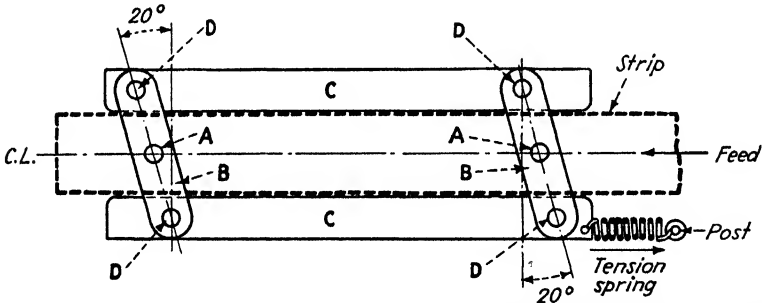
FIG. 423.—Centralizing a die strip continuously by passing it through a parallelogram of bars.

will be cut equidistant from the strip edges, a parallelogram of bars is used. This principle is illustrated in Fig. 423. The whole mechanism operates in clearance slots provided in the bottom face of the stripper plate. The fulcrum pins A are press-fitted through the stripper plate. The bars B swing on the fulcrum pins, and by construction they control the parallel movements of bars C while the strip is fed along between them.

The design shown is used for centralizing narrow widths of strip, but for wider strips, bars C are omitted and hardened rollers about $1\frac{1}{4}$ in. in diameter are substituted under bars B, with their center holes mounted over pins D. A light tension spring is attached, as shown.

The spring forces the bars or rollers to be in contact against the edges of the strip constantly. This centralizing device has proved in practice that it will guide the strip symmetrically over the dies if the width and camber variations along the strip edges are within allowable commercial limits.

Weight and Approximate Thickness of Sheet Steel.—Sheet steel is gaged by the U.S. Standard gage. This is a weight and not a thickness gage. It was originally based on wrought iron at 0.2778 lb. per cubic inch or 480 lb. per cubic foot. The numbers, or gage thicknesses, were to give definite weight per square foot, No. 0000000 being 0.5 in. and wrought iron of this gage weighing 20 lb. per square foot.

Because steel has almost entirely superseded wrought iron for sheet use since the U.S. gage was established, the density of rolled steel, 0.2833 lb. per cubic inch, or 489.6 lb. per cubic foot, has been adopted by the Association of American Steel Manufacturers and the A.S.T.M. and approved by the Bureau of Standards. Thicknesses in the following table are of steel equivalent to the unit weights of the U.S. Standard gage. Steel is, however, rolled to any decimal thickness to meet requirements. In ordering, it is always best to specify the thickness in decimal fractions instead of using the gage numbers. This precaution applies to all sheet metals.

Sheets up to and including No. 5, or 0.2145 in., are called "sheets"—above this they are called "plates."

For the weight per square foot of any material not given in the following tables, use the weight per cubic inch of the given material as found on pages 28 and 29. Multiply the weight per cubic inch by 0.144 times the number of thousandths of an inch in the given material for the weight in pounds per square foot. For example, 1 cu. in. Stainless steel weighs 0.3033 lb.; then 1 sq. ft. 0.083 gage weighs 0.3033 × 0.144 × 83 or 3.625 lb.

U.S. Standard Gage for Sheet and Plate Iron and Steel

Gage No.	Approximate thickness in fractions of an inch	Approximate thickness in decimal parts of an inch	Weight per square foot in ounces avoirdupois	Weight per square foot in pounds avoirdupois
0000000	1–2	0.5	320	20.
000000	15–32	0.460	300	18.75
00000	7–16	0.429	280	17.5
0000	13–32	0.398	260	16.25
000	3–8	0.368	240	15.
00	11–32	0.337	220	13.75
0	5–16	0.306	200	12.5
1	9–32	0.2757	180	11.25
2	17–64	0.2604	170	'0.625
3	1–4	0.2451	160	10.
4	15–64	0.2298	150	9.375
5	7–32	0.2145	140	8.75
6	13–64	0.1991	130	8.125
7	3–16	0.1838	120	7.5
8	11–64	0.1685	110	6.875
9	5–32	0.1532	100	6.25
10	9–64	0.1379	90	5.625
11	1–8	0.1225	80	5.
12	7–64	0.1072	70	4.375
13	3–32	0.0919	60	3.75
14	5–64	0.0766	50	3.125
15	9–128	0.0689	45	2.8125
16	1–16	0.0613	40	2.5
17	9–160	0.0551	36	2.25
18	1–20	0.0490	32	2.
19	7–160	0.0429	28	1.75
20	3–80	0.0368	24	1.5
21	11–320	0.0337	22	1.375
22	1–32	0.0306	20	1.25
23	9–320	0.0276	18	1.125
24	1–40	0.0245	16	1.
25	7–320	0.0214	14	0.875
26	3–160	0.0184	12	0.75
27	11–640	0.0169	11	0.6875
28	1–64	0.0153	10	0.625
29	9–640	0.0138	9	0.5625
30	1–80	0.0123	8	0.5
31	7–640	0.0107	7	0.4375
32	13–1280	0.0100	6½	0.40625
33	3–320	0.0092	6	0.375
34	11–1280	0.0084	5½	0.34375
35	5–640	0.0077	5	0.3125
36	9–1280	0.0069	4½	0.28125
37	17–2560	0.0065	4¼	0.265625
38	1–160	0.0061	4	0.25
39	3–512	0.0057	3¾	0.234375
40	7–1280	0.0054	3½	0.21875
41	27–5120	0.0052	3⅜	0.2109375
42	13–2560	0.0050	3¼	0.203125
43	25–5120	0.0048	3⅛	0.1953125
44	3–640	0.0046	3	0.1875

The governing factors of this schedule are the weights given in the last two columns. The thicknesses shown are only approximate, and for steel plates and sheets the actual thicknesses will be somewhat less.

WEIGHTS OF STEEL, WROUGHT IRON, BRASS AND COPPER PLATES BIRMINGHAM OR STUBS' GAGE

No. of gage	Thickness in inches	Weight in pounds per square foot			
		Steel	Iron	Brass	Copper
0000	0.454	18.52	18.16	19.431	20.556
000	0.425	17.34	17.00	18.190	19.253
00	0.380	15.30	15.20	16.264	17.214
0	0.340	13.87	13.60	14.552	15.402
1	0.300	12.24	12.00	12.840	13.590
2	0.284	11.59	11.36	12.155	12.865
3	0.259	10.57	10.36	11.085	11.733
4	0.238	9.71	9.52	10.186	10.781
5	0.220	8.98	8.80	9.416	9.966
6	0.203	8.28	8.12	8.689	9.196
7	0.180	7.34	7.20	7.704	8.154
8	0.165	6.73	6.60	7.062	7.475
9	0.148	6.04	5.92	6.334	6.704
10	0.134	5.47	5.36	5.735	6.070
11	0.120	4.90	4.80	5.137	5.436
12	0.109	4.45	4.36	4.667	4.938
13	0.095	3.88	3.80	4.066	4.303
14	0.083	3.39	3.32	3.552	3.769
15	0.072	2.94	2.88	3.081	3.262
16	0.065	2.65	2.60	2.782	2.945
17	0.058	2.37	2.32	2.482	2.627
18	0.049	2.00	1.96	2.097	2.220
19	0.042	1.71	1.68	1.797	1.902
20	0.035	1.43	1.40	1.498	1.585
21	0.032	1.31	1.28	1.369	1.450
22	0.028	1.14	1.12	1.198	1.270
23	0.025	1.02	1.00	1.070	1.132
24	0.022	0.898	0.88	0.941	0.997
25	0.020	0.816	0.80	0.856	0.906
26	0.018	0.734	0.72	0.770	0.815
27	0.016	0.653	0.64	0.685	0.725
28	0.014	0.571	0.56	0.599	0.634
29	0.013	0.530	0.52	0.556	0.589
30	0.012	0.490	0.48	0.514	0.544
31	0.010	0.408	0.40	0.428	0.453
32	0.009	0.367	0.36	0.385	0.408
33	0.008	0.326	0.32	0.342	0.362
34	0.007	0.286	0.28	0.2996	0.317
35	0.005	0.204	0.20	0.214	0.227
36	0.004	0.163	0.16	0.171	0.181

WEIGHTS OF ALUMINUM, BRASS, AND COPPER PLATES AMERICAN OR
BROWN & SHARPE GAGE

No. of gage	Thickness in inches	Weight in pounds per square foot		
		Aluminum	Brass	Copper
0000	0.46	6.48	19.688	20.838
000	0.4096	5.77	17.533	18.557
00	0.3648	5.14	15.613	16.525
0	0.3249	4.58	13.904	14.716
1	0.2893	4.08	12.382	13.105
2	0.2576	3.63	11.027	11.670
3	0.2294	3.23	9.819	10.392
4	0.2043	2.88	8.745	9.255
5	0.1819	2.56	7.788	8.242
6	0.1620	2.28	6.935	7.340
7	0.1443	2.03	6.175	6.536
8	0.1285	1.81	5.499	5.821
9	0.1144	1.61	4.898	5.183
10	0.1019	1.44	4.631	4.616
11	0.0908	1.28	3.884	4.110
12	0.0808	1.14	3.458	3.660
13	0.0720	1.01	3.080	3.260
14	0.0641	0.903	2.743	2.903
15	0.0571	0.804	2.442	2.585
16	0.0508	0.716	2.175	2.302
17	0.0453	0.638	1.937	2.050
18	0.0403	0.568	1.725	1.825
19	0.0359	0.506	1.536	1.626
20	0.0320	0.450	1.367	1.448
21	0.0285	0.401	1.218	1.289
22	0.0253	0.357	1:085	1.148
23	0.0226	0.318	0.966	1.023
24	0.0201	0.283	0.860	0.910
25	0.0179	0.252	0.766	0.811
26	0.0159	0.225	0.682	0.722
27	0.0142	0.200	0.608	0.643
28	0.0126	0.178	0.541	0.573
29	0.0113	0.159	0.482	0.510
30	0.0100	0.141	0.429	0.454
31	0.0089	0.126	0.382	0.404
32	0.0080	0.113	0.340	0.360
33	0.0071	0.100	0.303	0.321
34	0.0063	0.0888	0.269	0.286
35	0.0056	0.0790	0.240	0.254
36	0.0050	0.0704	0.214	0.226
37	0.0045	0.0627	0.191	0.202
38	0.0040	0.0558	0.170	0.180
39	0.0035	0.0497	0.151	0.160
40	0.0031	0.0442	0.135	0.142

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